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THE SCIENCE OF NAVAL ARCHITECTURE.*

BY

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THE art of shipbuilding was undoubtedly developed at a very early stage of the history of the human race. The earliest record of a ship, as distinct from a boat, canoe, or other small craft, is found in Egyptian carvings of a date about 3000 B.C. But the science of naval architecture, like so many other branches of science, developed slowly, this science, as now accepted, being mainly a development of the last hundred years, we may almost say of the last fifty years.

The famous Swedish naval architect and shipbuilder, Henry de Chapman, published a treatise on shipbuilding in 1775. As late as 1820 we find Doctor Inman, the head of the Royal Naval College and School of Naval Architects in Portsmouth Dockyard, England, publishing a translation of Chapman for the instruction of English students of naval architecture. Chapman's work, so far as it deals with the science of naval architecture, consists largely of empirical rules, although it was far in advance of his day, and much of it is still applicable to sailing ships. In some respects his ideas were largely erroneous, an example being his theories regarding resistance of ships. In fact, it was not until a hundred years after Chapman's time that the science of naval architecture was enriched by sound theories concerning this important branch.

* Presented at the Stated Meeting of the Institute held Wednesday, May 16, 1917, when Dr. Taylor received The Franklin Medal in recognition of "His fundamental contributions to the theory of ship resistance and screw propulsion, and of his signal success in the application of correct theory to the practical design of varied types of war vessels in the United States Navy."

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Dealing with the sailing vessels concerning which Chapman wrote, Ruskin said:

"Take it all in all, a ship of the line is the most honorable thing that man as a gregarious animal has ever produced. By himself, unaided, he can do bettter things than ships of the line; he can do poems and pictures and other combinations of what is best in him. But as a being living in flocks and hammering out with alternate strokes and mutual agreement what is necessary for him in those places, to get or produce the ship of the line is his first work. Into that he has put as much human patience, common sense, forethought, experimental philosophy, self-control, habits of order and obedience, thoroughly wrought handiwork, defiance of brute elements, careless courage, careful patriotism, and calm expectation of the judgment of God as can well be put into a space 300 feet long and 80 feet broad, and I am thankful to have lived in an age when I can see this thing done."

This is what Ruskin thought and wrote years ago of the ship of his day. His words are even more true of the ship of our present day and generation. His 300 feet of length has trebled, and the size of such a ship, as measured in terms of weight, has grown nearly ten times. These modern ships have been made possible by the development of the science of naval architecture. This science, alone and unaided, without parallel development in practically all of the arts, sciences, and trades, could not have produced these ships; but, so far as the ship itself is concerned, all the great progress in every branch of science and industry could not have produced this concentrated embodiment of human intelligence without the development and advancement of naval architecture or the theory of shipbuilding, a branch of applied science which calls upon and draws from an exceptional number of the arts and sciences.

The modern battle cruiser, whose building is just being undertaken in this country, is an excellent example of the mutual agreement and coördination necessary between all the arts and sciences in the work of the naval architect. These vessels of ours will be of 35,000 tons displacement, and will be capable of a speed through the water of some 35 knots, or a little over 40 statute miles per hour. To drive this mass at this speed, there will be required a machinery installation capable of delivering 180,000 horsepower. The vessels are 850 feet in length; they will carry ten high-powered 14-inch guns as a main battery, with the addition of a large number of guns of smaller calibre, to say nothing of the torpedo tubes.

Let us consider very shortly a few of the sciences involved when we undertake to build such a vessel. It is hardly necessary to say that this undertaking would not have been possible without the slow, steady development, through the ages, of the various theorems of pure mathematics, which, in their applied forms, have been necessary to material progress in the various branches of engineering. In addition to its general application, mathematics has made possible the modern systems of control of the firing of the great guns, which permit them, with a considerable degree of accuracy, to drop a shell weighing a ton, on a comparatively small target, at a distance of 12 to 15 miles. This accurate control of fire is based largely on instruments or mechanisms which permit the instantaneous solution of problems containing as many as half a dozen variables.

Likewise, these ships could not be possible without the aid of astronomy, for it is through the development of that science, and through the experimental results made possible by it, that the various navigational instruments can be utilized to permit a sure and safe passage of the ship from one point of the earth's surface to another.

Chemistry has played its part, not only in its general contributions to all engineering progress, but also in its solution of specific questions and difficulties, such as are involved in the manufacture of propellent powders and high explosives in forms that may be safely handled and carried on such a vessel until the selected moment for turning loose their destructive forces. Chemistry, also, through its particular manifestation in the form of metallurgy, has played one of the most important parts, by providing numerous varieties of steel, ferrous alloys, and non-ferrous metals, which are used in the various parts of the ship and its equipment, many of these having been developed solely for the use to which they are put in such vessels as these.

Physics, in its various branches, has played a prominent rôle. In optics it has given us the theories of and has made practicable the various instruments which, in conjunction with fire control systems, make possible the accurate firing of guns and torpedoes, without which such a vessel would have no *raison d'être*.

Acoustics has played its part in the solution of many particular problems and difficulties, for, in the same way that coördination has been carried out in constructing the ship, the most

complete and harmonious coördination of all parts of its organization is necessary in her hour of trial by battle. This is rendered possible only by the most perfect means and instruments of communication throughout all parts of the vessel. These systems of communication must be such that they will not break down in the midst of the noises and confusion of battle, or because of the high mental tension, at such times, of the personnel using them.

The sciences of physiology, medicine, and hygiene must likewise play their parts, for, during the long years of peace, each of these vessels must be the healthful and, as far as possible, the happy home for anywhere from 1000 to 1500 men. This means that what we term in the navy "berthing and messing" facilities, or what in civil life would be referred to as the "housing and feeding" conditions, must be based on the most modern scientific principles. Likewise, to insure efficiency in battle, the design must take careful cognizance of what these sciences have taught us as to the limitations of human endurance when working at high pressure under adverse conditions. Nor do we stop at this point, for there is provided, in addition, a completely equipped medical establishment or hospital, including operating-rooms, isolation wards for contagious diseases, special examining and treatment rooms, dental facilities, etc.

Without further enumeration of the many other branches of science and engineering which necessarily enter into the design of one of these great ships, let us consider more closely the principal branches of naval architecture proper. This is, broadly speaking, the division of engineering which enables us to make use of accumulated progress and knowledge to produce one workable and efficient assembled unit in the form of a ship. Its branches closely parallel the primary operations necessary in the design of such a ship, as has been described. Given the fundamental requirements of the design, which in the naval service we term military characteristics, and which consist of a brief statement of the results which it is desired to obtain with the completed vessel in service, it is first necessary to make an estimate of the size of the ship which will permit a solution of the design problem. The first estimate or approximation must be based largely on previous practice and experience. Before the development of naval architecture, in its modern sense, the necessity usually involved rather slow step-by-step progress from

one ship to another. Naval architecture has now taught us how to make these steps much greater, so that during the last quarter of a century advances which would have been bold to rashness at an earlier time have become almost routine. The rule of step-by-step progress referred to above has at least one remarkable—we may almost say astonishing—exception. Some 65 years ago a famous English civil engineer and bridge builder turned to shipbuilding. Maintaining that the larger the ship the more economical and efficient her operation, Brunel attracted large capital and in association with Scott Russell, the shipbuilder and naval architect, finally produced the *Great Eastern,* which was indeed a giant by a pigmy when compared with the other iron steamships of her day. Her keel laid in 1854, launched in 1858 after many difficulties, and put in service in 1859, the *Great Eastern* was not a commercial success. She fell short of the expectations of her designers in many respects. The successful completion even in five years of such a vessel was truly a remarkable accomplishment, but her size was ahead of her day, and it was not until 1899 that we find it again reached. As already stated, progress is more rapid nowadays than heretofore, but even now naval architecture would hardly enable us to take, with confidence, such a leap as the *Great Eastern* promoters undertook.

When in the early stages of a design we have, based on previous practice and experience, reached a first approximation to the size of the vessel, it is next necessary to examine in detail the problems of strength, stability, resistance, and propulsion of the ship. These represent broadly the main divisions of our subject. Naval architecture, as a whole, and its branches, like engineering generally, has not yet become an exact science, and in some respects it appears impossible that this will ever be attained. The strength and stability of ships, for example, should be such as to enable them to withstand, under all conditions, the waves of the sea, but the latter are infinite in variety, and the attempt must be to provide for any manifestation arising from this variety. It is, therefore, not possible in a new problem to lay down an exact condition of water surface, and say that if our ship can stand this condition it can stand all others. The best we can do is to make an approximation of the most severe condition, based on previous accumulated experience and observation. There have been made many thousands of observations

on sea waves, but there is yet no complete agreement in regard to their limiting characteristics, such as length, height, and the relations existing between these dimensions.

About the middle of the last century Rankine gave us the first complete mathematical theory of the formation and character of waves, known as the trochoidal theory; his result had, however, been largely predicted by Grestner more than sixty years before. Although Rankine's theory does not explain and is not entirely consistent with all phenomena of this nature, it is generally accepted to-day as a reasonable and convenient approximation of the facts, and it is usually upon stresses due to waves such as result from Rankine's theory that we have our determinations of strength of vessels.

We find that from the very beginning of practical shipbuilding the problem of strength was recognized in concrete form, for in the very first ship of which we have historical record its picture shows what we now term a "hogging" girder, which was provided to take the strains resulting from the variation between distribution of weight and distribution of buoyancy. It was the existence of these strains, and the fact that they increased with increase in length of ships, that operated to limit the length and, consequently the size of ships during the era of wooden shipbuilding, as it was then, and still is impracticable to develop the full strength in end connections between contiguous wooden members. The introduction of iron and steel, in conjunction with the development of methods and mechanisms for riveting, has made the modern ship possible. For many years the provision of the necessary strength depended largely on rule-of-thumb methods and step-by-step development from one ship to another. Such methods, of course, led, in the majority of cases, to one of two results: either deficiency of strength, or excess of strength. For any structure erected on shore, the latter fault is not necessarily a serious one, except from the point of view of cost. On a ship, however, too much material is almost as grave an error as too little, for every ship is built to perform some distinct service, and, as a floating body, can carry for all purposes only the equivalent of the weight of water which it displaces. Every pound which goes unnecessarily into the structure of the ship itself is a dead loss to the aim or object for which the vessel is designed. The modern theory of longitudinal

strength for a vessel, as based on many years of observation and experiments, has its origin in the simple fundamental theories of strength of beams or girders. The ship's structure as a whole is considered as a built-up girder with upper and lower flanges and connecting webs. This girder is assumed to be supported on a wave of length equal to that of the ship. The height of this wave is assumed to have various relations to its length, depending upon the magnitude of that length, but for the majority of cases this relation is taken as one to twenty. This girder is then assumed to be supported in a manner represented by the buoyancy curve of the ship when floating on such a wave. The form of this buoyancy curve will, of course, vary with the position of the ship in relation to the crest and hollow of the wave, and in important strength calculations it is redrawn for at least two, and sometimes as many as six, positions. The loading of the girder is represented by the loading of the ship, including its own weight, that of permanent installations, such as propelling machinery, etc., and that of the variable or useful load carried. By successive integrations and the use of the simple beam formula we then arrive at the figures representing stresses and strains in the theoretical girder. Some experiments have been made from time to time, notably those of Biles in 1903, to check the accuracy of the results obtained by this method, but, due to the cost and magnitude of such experiments, there have never been collected sufficient data to enable us to say how accurately these results do represent the actual stresses in the ship in service. Accordingly, we are still largely dependent on comparing the figures obtained by this method for the new ship with those obtained by the same method for previous ships that have shown adequate strength in service.

Possibly due to the fact that our standard wave is not so steep as waves having the length of short ships, and steeper than waves having the length of long ships, it seems to have been thoroughly established by experience that, with the method outlined above, it is safe to allow larger stresses in large and long ships than in short and small ones. If, for instance, we find that by this method a small vessel in service shows satisfactory results when her figured standard stress is, say six tons in compression and eight tons in tension, and shows indication of weakness if these figures are materially exceeded, we would find that

also in service a very large and long ship would show no signs of weakness with calculated stresses as high as ten tons in compression and twelve tons in tension. This principle appears to have been acted upon, though the scientific principles underlying it were not fully understood, even in the early days of iron shipbuilding. This was brought out about fifty years ago, when our modern methods of figuring strength were first applied to ships built in accordance with the then existing rules of the classification societies, with the result that the large ships of that day were found to have indicated stresses in extreme cases nearly five times as great as those found in small ships.

There are, of course, a very large number of strength problems involved locally in ships themselves, and therefore particularly within the province of naval architecture, but these are, after all, secondary when compared with the problem of the strength of the main structure.

Turning now to stability, which is the measure of the ability of a ship to remain upright or to return to the upright when inclined by an external force usually impressed by varying conditions of water surface, we find that the full and exact treatment of this branch is of quite modern origin. In the earliest day adequate stability was largely dependent on carrying ballast, and the amount and location of such ballast were determined by trial. In other words, except by following more or less closely the model of a previous vessel, there was no means of determining in advance whether a proposed design would result in a satisfactory stability condition.

About the middle of the eighteenth century the French mathematician, Bouguer, made a long step in developing the science of stability by developing the concept of the metacentre. In mathematical language, the metacentre is the centre of curvature of the locus of the centre of buoyancy of the vessel as it is inclined. As a practical proposition the metacentre is the limit above which we cannot locate the centre of gravity of the ship without having her initially unstable and unable to remain upright. The position in space of this imaginary point depends upon the geometrical form and the dimensions of the ship. Perhaps a homely illustration may clarify the matter. If you take an ordinary rocking-chair and attach a weight to it in such a manner that the centre of gravity of the chair and the weight is above the centre

of curvature of the rocker, the chair will not stay put and will loll over and capsize. If the centre of gravity is materially below the centre of curvature of the rocker, which is the case when one sits in an ordinary rocking-chair, the chair will remain in a fixed position; if the rocker is very flat, resulting in a greater distance of the centre of gravity below the centre of curvature, the chair will be stiff and harder to rock or heel from the upright position. The metacentre of a ship corresponds very closely with the centre of curvature of the rocker as already described.

After Bouguer developed the conception and mathematical methods for calculating the position of the metacentre, Atwood carried the matter further by calculating the righting arm or lever, which, multiplied by the weight involved, measures the torque when a vessel is inclined. The metacentric conception applies only to initial stability with the vessel upright, and for many years appears to have been sufficient, particularly as applied to sailing ships, which were very much of the same general type, with comparatively small variations of general form, relative freeboard, etc.

Something more than fifty years ago, however, the loss of the *Captain* brought home very strongly to naval architects, particularly in England, the fact that there was another factor involved in stability. A distinguished English officer, Captain Cowper Coles, took up with enthusiasm the monitor idea, first developed by Ericsson in this country, and as a result of his campaign there was built in England a low freeboard vessel called the *Captain*, with turrets and also full sail power. Naval architects of the English Admiralty were not enthusiastic over the type. The vessel had much less metacentric height than the pure monitor type, but early reports and experience with her indicated that she would be a great success, until on the night of September 7, 1870, in the Bay of Biscay, with a moderate gale blowing, she capsized, with a loss of 481 lives, including Captain Coles himself. The vessel was perfectly safe until conditions were such that she heeled over enough to bring her deck edge well under water. After that her righting force rapidly decreased, and at a comparatively small heel became negative, resulting in capsizing. Under the weather conditions existing the force of the wind against the sails of the *Captain* was sufficient to heel her beyond the safety angle, and over she went.

The investigation into this disastrous occurrence brought out the fact that a vessel with a comparatively small metacentric height may be perfectly safe if it retains a righting tendency at a large angle of inclination—a feature associated primarily with high freeboard. On the other hand, a low freeboard vessel, with a comparatively short range of stability, may also be perfectly safe if its metacentric height and initial stability are very great, so that a large amount of work has to be done to incline the vessel throughout its comparatively short range of stability.

This whole question is now fairly well understood, and the naval architect is enabled to adjust his metacentric height as he will by varying proportions and dimensions of the ship to suit the position of the centre of gravity and type of vessel—all requiring very careful and detailed calculations. As a matter of fact, there are passenger vessels crossing the Atlantic in perfect safety with no initial stability, or even with a slightly negative metacentric height, their freeboard and shape giving them a range of stability of as much as 90 degrees.

Since the days of Fulton's first steamboat the design of vessels' hulls, on such lines as to give the minimum resistance in passage through the water at varying speeds, consistent with the other characteristics of the ship, has become increasingly important. This is well illustrated in the case of the new battle cruisers, to which I have already referred. To arrive at the most advantageous dimensions and form of hull, for purposes of the high speed desired, there were made and tested in the Model Tank, at Washington, upwards of twenty models, with the result that the resistance of the model finally adopted was nearly fifteen per cent. less than that of the first model tried.

I would particularly invite attention to the fact, however, that this was by no means due to improvement in shape of lines alone, but also to other changes which were adopted with some reluctance, but which it was known in advance would materially reduce the resistance. Experience in recent years has fully confirmed the conclusion drawn from Model Basin investigations that, for high-speed vessels, the length is a primary factor. In fact we know in the majority of cases of high speed vessels that we could reduce resistance by increasing the length. This usually involves, however, increased weight of hull and other objections. So that for large, fast vessels the naval architect usu-

ally adopts dimensions which do not give the minimum resistance for the displacement, but the best all-around result, considering the total weight, including both hull and machinery.

Men-of-war in particular are generally made relatively shorter than merchant vessels, for the reason that ordinarily they travel at a low speed, and the long vessel requires more power at low speed than the short vessel, and hence on a given endurance requires a greater weight of fuel. The merchant vessel, particularly the fast passenger vessel making its passages at top speed or thereabouts, must be economical at that speed.

A hundred years ago the ideas of ship resistance were entirely crude, the usual opinion being that the resistance was in proportion to the area of the cross-section of the vessel which had to be forced through the water. About the middle of the last century Rankine put forward a theory which went to the opposite extreme. His proposition was that in a well-formed vessel the resistance was entirely due to the friction of the surface against the water, and he developed a method for estimating this. Our modern ideas on this subject are due primarily to William Froude, the originator of modern experiments, which have been the most useful appliance of research in this line one could imagine. The "law of comparison," by which, from the resistance of a small model at low speed, we can closely estimate the resistance of a large ship at high speed, is commonly called by naval architects "Froude's Law." It appears to have been originated independently by Mr. Froude, although, as a matter of fact, it is a particular case of the general law of mechanical similitude, apparently first enunciated by Newton.

The resistance of ships by the Froude methods is regarded as made up of three elements: The friction of the surface, which, for low-speed vessels, may be as much as 90 per cent. of the total, and seldom falls below 50 per cent., even for very fast vessels; the wave-making resistance, due to the energy required to create and maintain a system of waves accompanying the motion of the ship through the water; and the eddy resistance, due mainly to eddies behind stern-posts, struts, and other appendages, and hence quite a small factor in the total. The "law of comparison" applies with great accuracy to the wave-making resistance, and with reasonable accuracy to eddy resistance. To frictional resistance it is not applicable, but Mr. Froude, by experiments on surfaces,

established coefficients of frictional resistance which are used to this day, although for some time naval architects have felt that it would be desirable to revise these coefficients upon the basis of experiments on a large scale. The procedure we use at the present time in obtaining the lines for a ship is about as follows:

By the use of tables and curves which have been produced as the result of years of experiment at the Washington Model Basin, certain coefficients, representing a form of under-water body, are selected, as giving a close approximation to the best solution of the particular problem in hand. By the use of these coefficients we can arrive at approximation to the best dimensions for any particular ship, and by the further use of certain standard forms of waterlines can draw, with little difficulty, the lines of the vessel. From the same data we can obtain a close approximation to the resistance, at varying speeds, of a hull built from these lines. These steps permit of settling the broad general characteristics of the design. The lines so drawn are then sent to the Model Basin, where a model to exact scale is built and its resistance accurately measured at varying speeds. In important designs, as in the case of the battle cruiser, this model will receive many variations in shape and refinements of details until it appears probable that the minimum resistance for such a hull has been reached. The resistance curve obtained from the final model is then used as the basis of the design of the machinery plant and propellers for the vessel.

There are, of course, many other divisions and subdivisions of naval architecture which enable us to foretell with a considerable degree of accuracy the behavior of a vessel under the many different conditions which may be met in a varied career of service, as, for instance, the degree of punishment which a ship can stand before sinking, when subjected to attack by gunfire, submarine torpedo, and mine and aerial bomb. These are factors which hitherto the naval architect has not been required to consider as regards merchant ships. If present piratical methods of war at sea are to continue, the distinction between merchant and war vessels will necessarily disappear.

As regards vessels of war, experience to date has shown broadly that the science of naval architecture has provided ships which function as anticipated. The enormously destructive weapons of the day are able to destroy in time anything that

floats, and without disparaging Mahan's dictum that "Good men in poor ships have always won over poor men in good ships," there is no doubt that good ships are essential even to the best men. Our ships are now to undergo the "trial by ordeal" of the features carefully and patiently planned in past years. May they prove worthy of the good men that man them! There is one final thought, however, which naval architects the world over feel to-day. The progress of late years, which has seemed rapid, will seem slow indeed by the side of the progress and development which must and will be made during the years just ahead of us.

The science of naval architecture, whether applied to vessels of war or peace, has a weighty part to play as the world undertakes to meet the changed conditions of war time and of the time after the war.

Zirconia, a New Refractory Product. ANON. (*La Chronique Industrielle*, vol. 40, No. 291, p. 8, May 2, 1917.)—The attention of electro-metallurgists has recently been directed to the value of zirconia or oxide of zirconium, whose refractory properties appear to be applicable to electric furnaces. Free zirconium exists in three forms: amorphous, crystalline, and graphitic. The crystalline form, with a density of 6.4, has a melting-point of approximately 2350° C. Only two minerals can be considered as commercial sources of zirconium: the natural oxide and the silicate. Natural zirconia contains 84 per cent. of the pure oxide, with 8 per cent. of silica and 3 per cent. of oxide of iron. Purified, zirconia is a white substance with a density of 5 and, according to Weiss, a temperature of fusion of 3000° C.

The first important application of the oxide of zirconium was as a substitute for the cylinders of chalk in the Drummond light. This oxide was employed in the manufacture of incandescent gas mantles, but was later superseded by thorium oxide, which gives equally good results at lower temperature. Another application was effected in 1887 in the production of the Nernst lamp. Mixed with 10 per cent. of magnesia, with a binder consisting of starch, phosphoric acid, and glycerin or its borates, a product is obtained impermeable to liquids and unaffected by strong or fused alkaline mixtures. Its uses in metallurgy are very promising. In trials of a Martin furnace in a steel works at Remscheiden, Germany, a lining of zirconia was found in good condition after a run of four months, and apparently capable of another four months' service without repair.

Preliminary Study of the Alloys of Chromium, Copper, and Nickel. D. F. MCFARLAND and O. E. HARDER. (*Bulletin No. 93, Engineering Experiment Station of the University of Illinois.*)—The growing interest in special acid-resisting alloys and the many uses found for them have stimulated both the search for efficient materials of this nature and the study of the underlying causes of their inertness. Previous studies at the University of Illinois have shown that the almost perfect insolubility of certain alloys in nitric and other acids seems to be conditioned upon a proper mixture of chromium, copper, and nickel, together with smaller quantities of such added metals as tungsten or molybdenum.

As a result of further studies, methods have been developed for making castings of alloys of chromium, copper, and nickel. Twenty-one binary and thirty ternary alloys have been prepared, and physical and chemical tests have been made to determine the properties of the various alloys. More than 300 corrosion tests have been made to measure the effects of acids upon metals. In general, the results indicate that certain of the alloys of chromium, copper, and nickel give promise of becoming of great commercial importance not only in the construction of laboratory apparatus, but also in manufacturing and chemical processes in which the handling of acids is involved.

Copies of Bulletin 93 containing the results of these tests may be obtained gratis from C. R. Richards, Director of the Engineering Experiment Station, Urbana, Ill.

Reducing Prints on Printing-out Paper. ANON. (*Revue Scientifique*, vol. lv, No. 7, p. 209, March 24–31, April 7, 1917.)—Many formulas for the reduction of over-dense photographic negatives have been published, while the reduction of prints has seemingly aroused little interest. Nevertheless, the operation has value in the latter field, particularly when the prints are of large size and the paper is of a costly grade. The method employed is applicable to old prints, as it is necessary to work with a toned washed-and-dried print. The print is immersed into a solution of water, 100; hyposulphite of soda, 10; one per cent. solution of bichromate of potash, 3. Reduction begins at once and proceeds evenly. When the print is sufficiently reduced, it is thoroughly washed and dried. Most papers so treated retain their original color, though a few braids have a tendency to assume a blue-violet tone. The formula gives good results with gelatin papers. Collodion papers require a somewhat different treatment. The untoned print is washed and then immersed in a solution of water, 100; one per cent. solution chloride of gold, 1; hydrochloric acid, 1. The image at first appears to become spotted, but after a few minutes the reduction takes place evenly, while the toning proceeds normally, the color gradually changing from a brick-red to purple. When the image is sufficiently reduced, the print is fixed in a five per cent. solution of hyposulphite of soda. The tone is not altered either in fixing or drying, and the prints are of fine color and are permanent.

MODERN DYNAMO ELECTRIC MACHINERY.*

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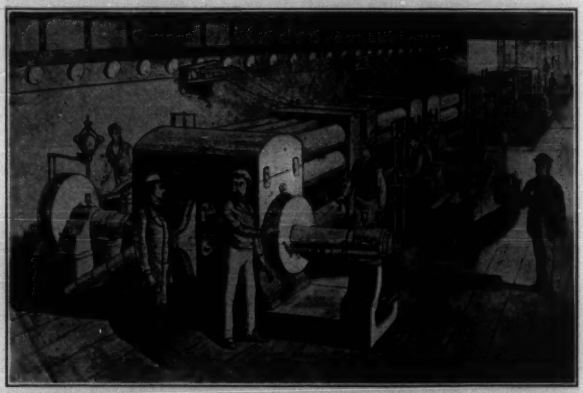
INTRODUCTION.

In few fields of human endeavor has there been such remarkable progress in the last thirty years as in electrical engineering. It is true that eighty-six years have elapsed since the principle of magneto-electric induction was discovered by Faraday, and that this discovery was immediately followed by the production of

FIG. 1.

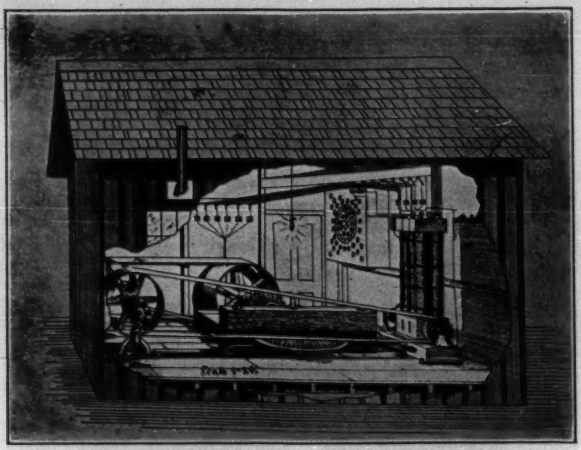


Generating station of 1882 with 125-horsepower, direct-connected units. The parallel field coils and the forced ventilation are of interest.

electric generators in large variety, which by 1865 were no longer mere laboratory machines, nevertheless these generators did not begin to assume great commercial importance until about 1880, by which time electric lighting had taken such a hold as to warrant the construction of central stations. Two of these early stations, installed in 1882, are shown in Figs. 1 and 2. The

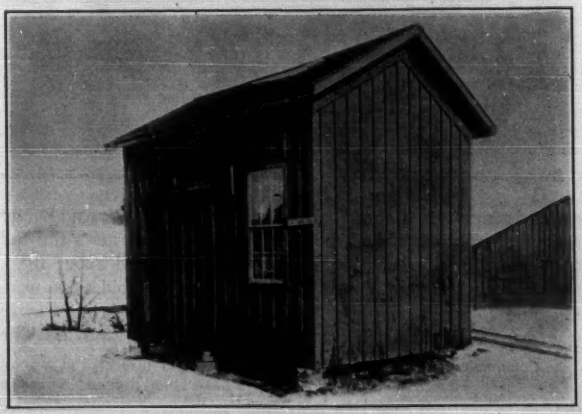
* Communicated by the Author. Based on a paper presented at a joint meeting of the Electrical Section and the Philadelphia Section, American Institute of Electrical Engineers, held Thursday, February 8, 1917.

FIG. 2.



Hydro-electric station of 1882 with a connected load of 250 incandescent lamps. The long poles and the parallel field coils are now obsolete.

FIG. 2A.



Exterior of the above power station.

Pearl Street station of the Brooklyn Edison Company started operation with a connected load of 2323 incandescent lamps, and the generators, which were direct connected and had a capacity of 125 horsepower, were considered so large in those days that they were generally known as Edison Jumbos.[1] The hydro-electric station at Appleton, Wis., was much smaller and had a connected load of only 250 lamps.

The great expansion in electric lighting which started about 1886 led to a gradual increase in the size of the central station, while the size of the individual unit increased from the 125-horsepower machines of 1882 to the 800-kilowatt units installed by the Brooklyn Edison Company in 1891,[2] and the 1500-kilowatt

FIG. 3.

First Niagara station with its 4000-kilowatt units. These machines were in operation only 13 years after the installation of the machine shown in Fig. 2.

unit exhibited at the World's Fair in Chicago in 1893.[3] These machines were all direct connected and helped to make that practice standard; most of the early stations had high-speed generators belted to slow-speed engines, and the most conspicuous things in some of these early stations were leather, static, and stray fields.

By 1900 the design of direct-current machines had become somewhat standardized, the various criteria for a good design

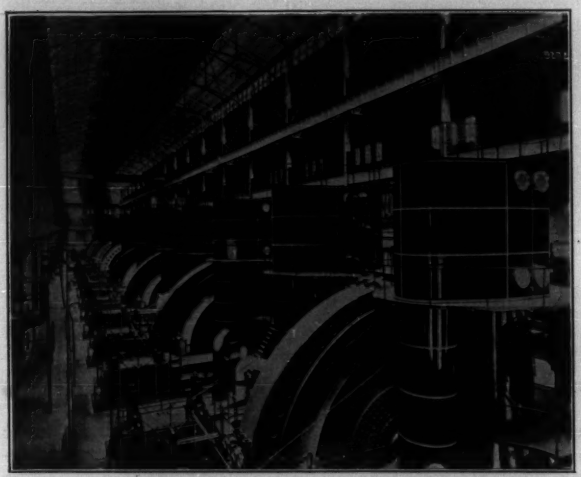
[1] "History of the Brooklyn Edison Company," *Electrical Engineering*, New York, vol. 21, p. 25.

[2] "History of the Brooklyn Edison Company," *Electrical Engineering*, New York, vol. 21, p. 25.

[3] For data on this machine, see "Electric Generators," by Parshall and Hobart, published 1900.

having become pretty well understood. With that date as a starting point, we shall show how the output for a given amount of material has gradually increased as the accumulated test data on actual machines allowed designers to work closer to the limits, while the gradual introduction of interpoles, which has led to a new conception of what is meant by sparkless commutation, has made it possible to build machines to carry overloads, operate at high speeds and through a wide range of speed in a way that most people considered impossible only ten years ago.

FIG. 4.



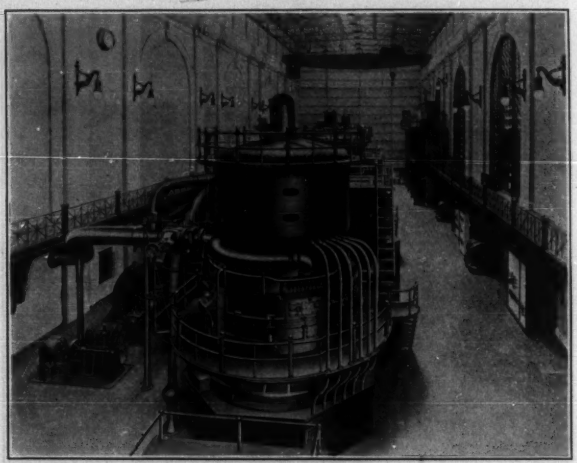
The Manhattan generators, designed in 1899. At the time of their erection they were the largest engine-driven dynamos that had ever been built.

The early central stations were built to supply direct currents, but, as the radius of distribution gradually extended, the subject of alternating currents forced itself on central station engineers. In 1886 the Westinghouse Company began the development of alternating-current machinery; in 1888 the induction motor was invented; in 1890 the Telluride Company transmitted power economically for a distance of fifteen miles, and in 1895, only thirteen years after the Appleton station had been installed, the water

was turned into the 4000-kilowatt units of the first Niagara station.

The size of the alternating-current generator kept on increasing, and at the time of their erection in 1901 the machines shown in Fig. 4 were the largest engine-driven dynamos that had ever been built. These machines are of a type that has been entirely superseded by the turbo-alternator, which began to make itself felt as early as 1903, when the 5000-kilowatt vertical Curtis turbo

FIG. 5.



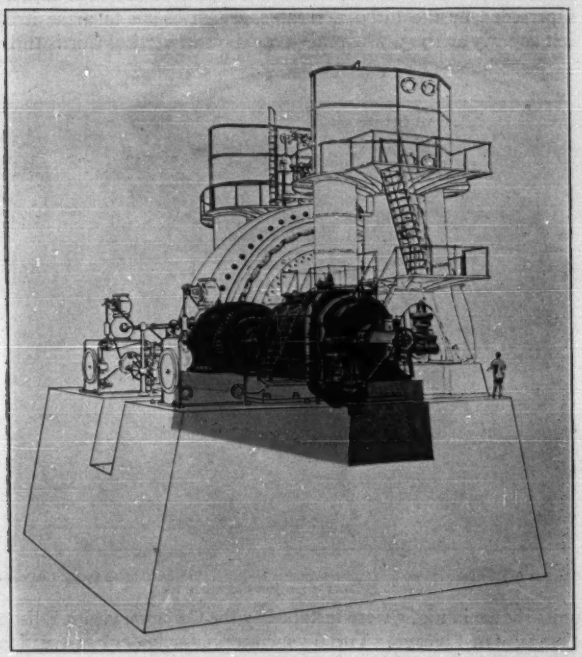
The first Curtis turbo-alternator of 5000 kilowatts capacity. It was installed by the Commonwealth Edison Company of Chicago in 1903.

units shown in Fig. 5 were installed by the Commonwealth Edison Company of Chicago. Turbo-generators now under construction include a single machine of 45,000 kv.a. capacity, also a 70,000-kv.a. three-machine unit which has one high- and two low-pressure turbine wheels, each direct connected to its own generator.

One of the great advantages of the turbo alternator is well shown in Fig. 6, and since this picture was taken, the output for a given size of machine has been more than doubled. This latter

development, which will be studied in greater detail, while partly due to improvements in ventilation, has been almost entirely due to the use of mica insulation and to the development and gradual introduction of a satisfactory voltage regulator.

FIG. 6.

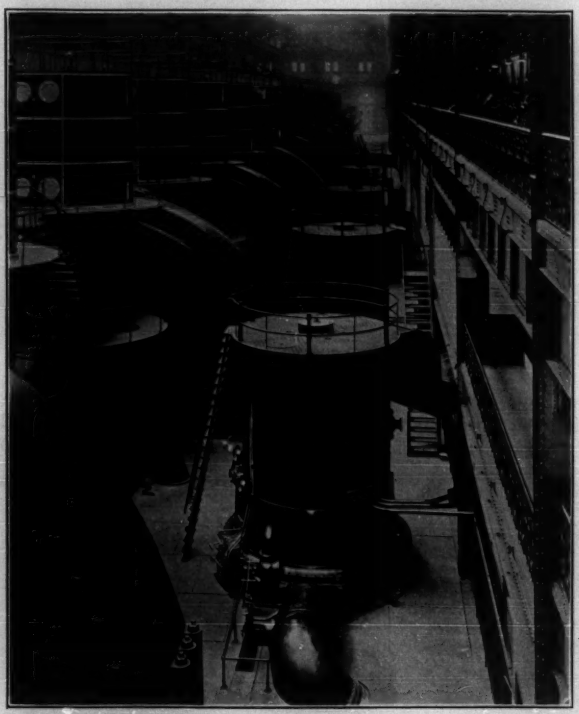


Relative dimensions of an engine-driven alternator and of a turbo-alternator of the same capacity.

Another type of machine on which remarkable progress has been made in the last ten years is the 60-cycle rotary converter. Up until 1909 the record of these machines was so poor that few manufacturing companies would undertake their construction, while most operating engineers preferred motor-generator

sets. To-day, however, satisfactory 600-volt, 60-cycle rotaries can be had of 2500-kilowatt capacity at 400 revolutions per minute. This result, as we shall see later, has been made possible

FIG. 6A.



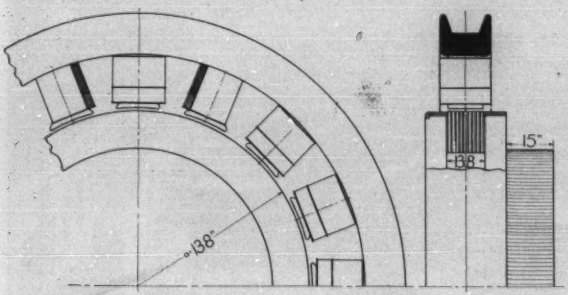
Engine-driven generators of 5000 kv.a. at 75 r.p.m. installed in 1901, and Curtis low-pressure turbo-alternators of 7500 kv.a. capacity installed in 1909.

in a large measure by improvements in the manufacture of high-speed commutators and by the addition of interpoles to make high-speed commutation satisfactory.

RECENT DEVELOPMENTS IN DIRECT-CURRENT MACHINERY.

It has already been pointed out that the design of direct-current machinery had become somewhat standardized by 1900.[4] In the following year a well-known machine was built from designs furnished by Hobart, the important constants of which are given

FIG. 7.



Hobart's generator of 1901. Capacity 1000 kilowatts, 500 volts, 90 r.p.m.

in Table I and the principal dimensions in Fig. 7. Since this machine represents the best practice of that time, it will be well to examine it carefully to find out why the output was limited to 1000 kilowatts.

TABLE I.

Kilowatts	1,000
Volts, no load	500
full load	500
Amperes	2,000
Revolutions per minute	90
Poles	16
Slots per pole	24
Size of slot	0.53 inch x 1.26 inch
Conductors per slot	6
Size of conductor	0.11 inch x 0.49 inch
Type of winding	One turn per coil, multiple
Tooth/slot	1.13
Maximum tooth density at no load	142,000 lines/square inch
Core	59,500 lines/square inch

[4] For an account of the early history of electrical machinery, see "Dynamo Electric Machinery," by S. P. Thompson.

For an account of the engineering evolution of direct-current machines in America, see Lamme, *Electric Journal*, vol. 12, pp. 65, 115, 164, 212.

TABLE I.—(*Continued*)

Pole	92,000 lines/square inch
Yoke	64,000 lines/square inch
a. Ampère conductor per inch of periphery	665
b. Circular mils per ampère	550
Ratio *a*/*b*	1.21
Peripheral velocity of armature	3,250 feet per minute
c. Ampère turns for tooth and gap at full load	9,300
d. Armature ampère turns per pole	9,000
Ratio *c*/*d*	1.04
Air-gap clearance	0.4 inch
Pole enclosure	71 per cent.
Commutator segments	1,152
Commutator segments covered by brush	2.72
Current density in brush contact	32 ampère/square inch
Average reactance voltage	2.5

The output might have been increased by increasing the flux per pole, but this would have necessitated wider teeth and therefore narrower and deeper slots, because the flux density in the teeth has already reached the high value of 142,000 lines per square inch. The output might also have been increased by increasing the current rating of the machine, which, of course, would have necessitated conductors of larger cross-section to carry the current and deeper slots in which to carry the conductors. Why, then, was the slot depth limited by Hobart to 1.26 inches, and why, in those days, was the criterion of a good design that the slots be wide and shallow?

COMMUTATION AND REACTANCE VOLTAGE.—It was early recognized that for satisfactory commutation the brush contact resistance should be large and the voltage of self-induction of the coils undergoing commutation should be small. The first satisfactory method by which an approximation to the value of this voltage of self-induction could be obtained was given by Hobart,[5] who developed a formula somewhat as follows:

The flux linking the coil *M*, Fig. 8, due to the currents that are being simultaneously commutated in the short-circuited coils, is

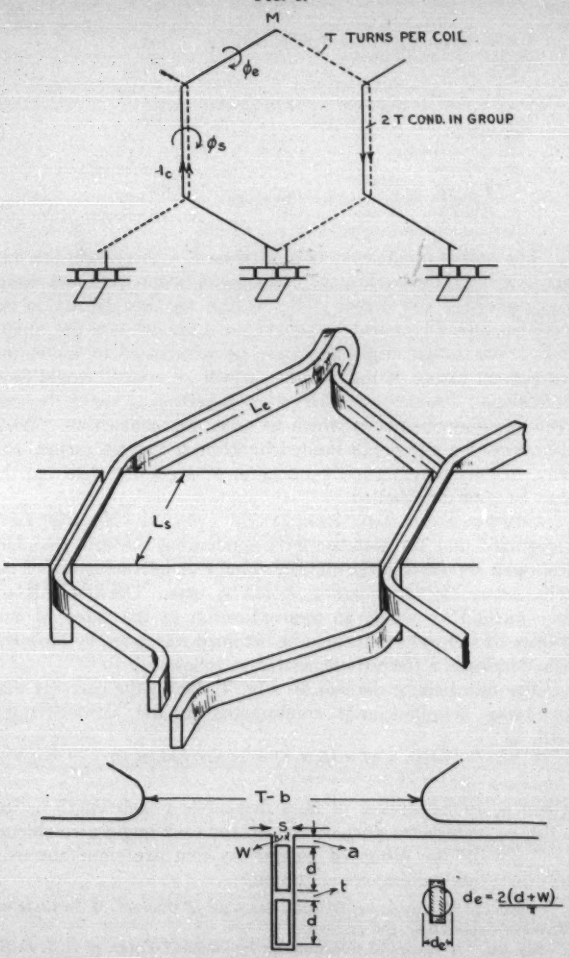
$$\phi_a = (\phi_s \times 2T \times 2L_s \times I_c) + (\phi_e \times T \times 2L_e \times I_c)$$
$$= 2T\, I_c\, (2\phi_s L_s + \phi_e L_e)$$

where ϕ_s is the number of lines that circle 1 inch length of the embedded part of coil *M* for each ampère conductor in the group of conductors that are simultaneously undergoing commutation.

[5] "Modern Commutating Dynamo Machinery," *Journal of Institute of Electrical Engineering*, vol. 31, 1901.

See also "A Theory of Commutation by Lamme," *Trans. of A. I. E. E.*, vol. 30, 1911 (p. 2359).

FIG. 8.



Commutation of the current in a full pitch winding.

ϕ_e is the number of lines that circle 1 inch length of the end connections of coil M for each ampère conductor in the group of end connections that are simultaneously undergoing commutation.

T is the number of turns per coil.

This flux is reversed in a time of $T_c = \frac{1}{SR}$ second,

where S is the number of commutator segments.

R is the speed of the machine in revolutions per second,

so that the average voltage of self- and mutual induction generated in coil M is

$$RV_{av} = \frac{2\phi_a}{T_c} \times T \times 10^{-8}$$
$$2\phi_a \times T \times R \times S \times 10^{-8}$$
$$= 4T^2 I_c RS(2\phi_s L_a + \phi_e L_e)10^{-8} \text{ volts.}$$

For standard machines Hobart has found by experiment that ϕ_s is approximately equal to 10 lines and ϕ_e to 2 lines of force, also that RV_{av}, as calculated by the above formula, should not exceed 2.5 volts.[6]

In the given machine we find

S = 1152.
R = 15 revolutions per second.
I_c = 2000/16 = 125 ampères.
L_s = 13.8 inches.
L_e = 43 inches.

Also, that the brush covers 2.72 commutator segments, so that at certain instants three adjoining coils are simultaneously undergoing commutation.

Therefore,

$$RV_{av} = 4 \times 125 \times 15 \times 1152\ (2 \times 10 \times 13.8 + 43 \times 2) \times 10^{-8} \times \frac{3}{2.72}$$
$$= 3.42 \text{ volts.}$$

Values of ϕ_s and ϕ_e more nearly accurate may be computed by the aid of the formulæ given by Arnold,[7] the first of which

[6] Hobart makes the assumption that the current reversal during commutation follows a sine law, and the reactance voltage, as he defines it, is $\pi/2$ times the value given by the above formula.

[7] "Die Gleichstrommaschine," vol. i, pub. 1906, p. 397.

formulæ shows the effect of slot depth on reactance voltage:

$$\phi_s = \frac{2.54 \times 4\pi}{s \times 10}\left[\frac{d}{1.5} + \frac{t}{4} + a + .735 \log_{10}\left(1 + \frac{\pi(\tau - b)}{2s}\right)\right] \text{ (see Fig. 8).}$$

$$= 6.1$$

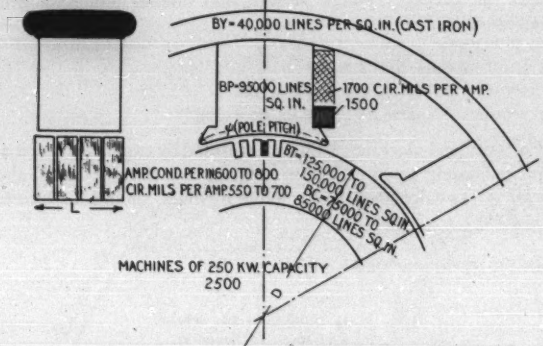
$$\phi_s = 2.54 \times .46(\log_{10} \frac{L_e}{d_e} - .2).$$

$$= 2.16$$

$RV_{av} = 2.5$ volts.

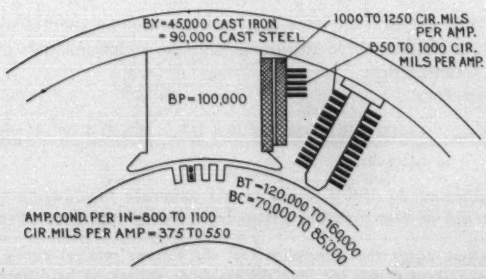
This value of reactance voltage is already close to the safe limit, so that it would not have made the

FIG. 9.


BY=40,000 LINES PER SQ. IN. (CAST IRON)
BP=95000 LINES SQ. IN.
1700 CIR. MILS PER AMP. 1500
τ (POLE PITCH)
BT=125,000 TO 150,000 LINES SQ. IN.
BC=75000 TO 85000 LINES SQ. IN.
AMP. COND. PER IN 600 TO 800
CIR. MILS PER AMP. 550 TO 700
L
MACHINES OF 250 KW. CAPACITY
2500

Limits of flux and current density in direct-current generators of 1907.

FIG. 10.


BY=45000 CAST IRON
=90,000 CAST STEEL
1000 TO 1250 CIR. MILS PER AMP.
850 TO 1000 CIR. MILS PER AMP.
BP=100,000
BT=120,000 TO 160,000
BC=70,000 TO 85,000
AMP. COND. PER IN=800 TO 1100
CIR. MILS PER AMP=375 TO 550
MACHINES OF 250 TO 2500 KW. CAPACITY

Limits of flux and current density in direct-current generators of 1917.

slots deeper or to have attempted the reversal of a larger current.

In an endeavor to improve commutation the brushes in these early machines were placed in such a position that the short-circuited coils were under the pole tips and in a magnetic field of such value as to cause a voltage to be generated in them equal and opposite to the voltage of self-induction. The strength of this reversing field should increase directly with the current to be commutated, but, due to armature reaction, it actually decreases as the load on the machine is increased. To minimize this effect of armature reaction the air-gap must be made reasonably large to cut down the cross-field, and then a sufficient number of ampère turns put on the poles to send the main flux across the air-gap, so that another criterion for the sparkless commutation of the type of machine built in 1900 was that the ampère turns on the main pole required to send the flux across the gap and tooth part of the magnetic circuit should be at least twenty per cent. greater than the armature ampère turns per pole. By this means a fairly stiff field was found under the pole tip even at full load, and the usual practice was to shift the brushes as far into this field as possible without causing sparking at no-load, and to rate the machine at that load which did not cause sparking in this position.

LIMITATIONS IN DESIGN IN 1907.—Let us now tabulate the limitations in design as recognized by designers ten years ago. The reader will find it of interest to compare the figures with those that were adopted by Hobart in 1901. These limitations, given in Fig. 9, are as follows:

Permeability which limits the flux density to

95,000 lines per square inch in the pole cores.
40,000 lines per square inch in cast iron yokes.
90,000 lines per square inch in cast steel yokes.
150,000 lines per square inch in armature teeth.

Higher densities would indeed allow a corresponding reduction in the cross-section of the yoke and core, but this would be at the expense of the increased copper required for the additional excitation.

Core Heating.—This is kept down to a reasonable value by limiting the tooth and core densities to approximately the following values:

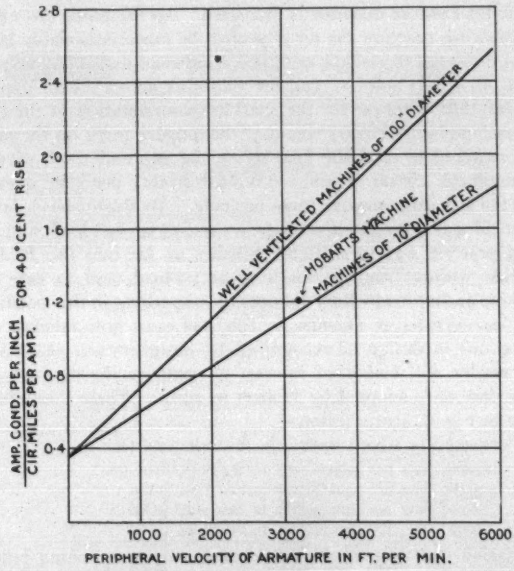
Maximum tooth density	=	150,000 lines per square inch below 30 cycles.
		125,000 lines per square inch at 60 cycles.
Average core density	=	85,000 lines per square inch below 30 cycles.
		75,000 lines per square inch at 60 cycles.

Copper Heating.—The copper loss to be dissipated by each inch of armature periphery is proportional to the ratio

$$\frac{\text{ampères per conductor} \times \text{conductors per inch of periphery}}{\text{circular mils of copper section per ampère}}$$

The higher the peripheral velocity of the armature, the higher can be this ratio. Safe values for large machines are given in Fig. 11.

FIG. 11.



Heating curves for armature and connections (1910); values 20 per cent. higher are often found in machines of 1917.

Commutation.—As already pointed out

Ampère turns (gap + tooth) > 1.2 (armature ampère turns per pole);

also the reactance voltage

$$RV = 4T^2I_cRS(20L_a + 2L_e)10^{-8}$$

should not exceed 2.5 volts, unless the commutating field is stiffer than usual or the brushes of higher contact resistance. A comparison between Figs. 9 and 10 will be found of interest.

THE OUTPUT EQUATION.—It will be advisable at this point to pick out the factors on which the output directly depends and find out wherein they are limited.

Watts output = volts per conductor x ampères per conductor x πD (conductors per inch of periphery).

= (lines cut per conductor per second x 10^{-8}) x πDq (see Fig. 9).

Therefore $\frac{\text{watts}}{\text{r.p.m.}} = \left(\frac{B_g \psi}{6.08 \times 10^8}\right) D^2 L$

$= KD^2L$

where K is called the output constant.

D is the armature diameter in inches.

L is the axial length of the core in inches.

B_g is the apparent gap density in lines per square inch

ψ is the per cent. pole enclosure = pole arc/pole pitch.

q is the ampère conductors per inch of periphery.

The fact that the heating of the armature depends on the value of q, the ampère conductors per inch, has already been pointed out; its further importance is emphasized by S. P. Thompson, who states: "If the design is such that not more than 200 ampères are to be collected at any one set of brushes, if the average flux density in the gaps is not less than 40,000 lines per square inch, and if the teeth are well saturated, the machine will run sparklessly if the number of ampère conductors does not exceed 650 per inch of the periphery of the armature." [8]

It has been customary to plot values of K against kilowatt output as in Fig. 12. These curves show how the output factor has increased in the last thirteen years; the reasons for this increase we shall now discuss.

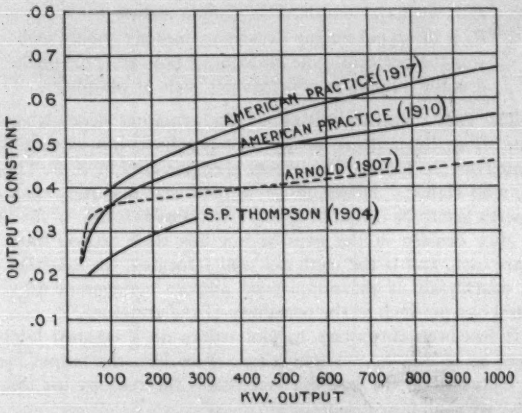
The value of B_g is limited by the permissible value of the tooth density, so that the greater the ratio of tooth/slot the larger the permissible value of B_g. This ratio seldom exceeds 1.10 in the non-interpole type of machine, and a larger value can be obtained only by the use of deep slots, which generally results in poor commutation. Average values of B_g for frequencies up to 30 cycles are given in Fig. 13; at higher frequencies the values are somewhat less. The smaller the armature diameter the greater the tooth taper and the lower the gap density for a given density at the root of the teeth.

[8] "Dynamo Electric Machinery," vol. i (published 1906), p. 276.

The value of q, the ampère conductors per inch of periphery, is also limited by commutation, because an increase in its value requires a corresponding increase in the cross-section of copper so as to keep the copper loss per inch of periphery unchanged. For a given temperature rise, therefore, the slot depth increases as the square of the value of q and commutation soon becomes unsatisfactory.

The value of ψ is limited by the leakage flux. If the pole pitch of a machine is increased, the armature ampère turns per pole, and therefore the length of the air-gap, increase in the same

FIG. 12.



Values of the output constant.

ratio, and the leakage flux between the pole tips will increase with respect to the flux crossing the gap unless the interpolar space is also increased. It is usual, therefore, to limit the pole arc to 0.7 times the pole pitch. If a greater value is used the leakage flux becomes excessive, while with a smaller value too large a percentage of the armature surface is inactive.

Up to 1910 the increase in the output factor was due principally to improvements in brushes and to the accumulation of test data that allowed designers to work closer to the limit and gradually raise the value of q. The last increase over the values of 1910 has been due to the gradual introduction of interpoles.

With non-interpole generators it is usual to shift the brushes forward from the geometrical neutral so that the short-circuited coils are under the pole tips and in a reversing field. In the interpole generator, on the other hand, the pole tips are shifted backwards so as to influence the short-circuited coils, and series windings are placed around them to make the strength of the reversing field directly proportional to that of the current to be reversed. With commutation thus taken care of, it would seem that there could be no objection to the use of deep and narrow slots and to a large increase in the value of q and of the ratio tooth/slot, and yet it may be seen from Fig. 12 that since inter-

FIG. 13.

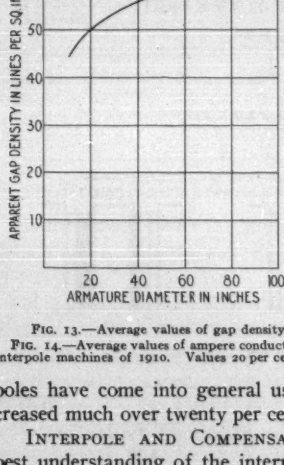


FIG. 14.

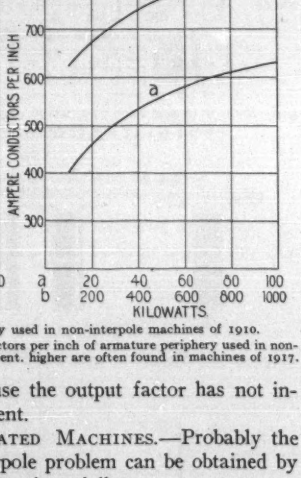


FIG. 13.—Average values of gap density used in non-interpole machines of 1910.

FIG. 14.—Average values of ampere conductors per inch of armature periphery used in non-interpole machines of 1910. Values 20 per cent. higher are often found in machines of 1917.

poles have come into general use the output factor has not increased much over twenty per cent.

INTERPOLE AND COMPENSATED MACHINES.—Probably the best understanding of the interpole problem can be obtained by the working out of an actual example as follows:

Kilowatts	1,200
Volts	720
Ampères	1,670
Revolutions per minute	600
Poles	8

Slots per pole	14
Size of slot	0.54 inch x 1.5 inch
Conductors per slot	6
Size of conductor	0.12 inch x 0.55 inch
Type of winding	One turn per coil; multiple
Tooth/slot	1.33
a. Ampère conductors per inch of periphery	1,000
b. Circular mils per ampère	400
Ratio a/b	2.5
Peripheral velocity of armature	7,000 feet per minute
Commutator segments	336
Segments covered by the brush	3
Average volts per segment = 720/segments per pole	17.1
Pole enclosure	0.7
Embedded length of conductor	16.5 inches
Length of end connection	27 inches

The reactance voltage if the brush arc were exactly equal to the width of one commutator segment would be

$$RV_{av} = 4\ T^2 I_c R\ S(2\phi_s L_s + \phi_e L_e)\ 10^{-8}$$

where $$\phi_s = \frac{2.54 \times 4\pi}{10s}\left[\frac{d}{1.5} + \frac{t}{4} + a + .73 \times s \times \log_{10}\left(1 + \frac{\pi(\gamma - b)}{2s}\right)\right]$$

$$= 5.9\ (.37 + .025 + .25 + .48) = 6.6$$

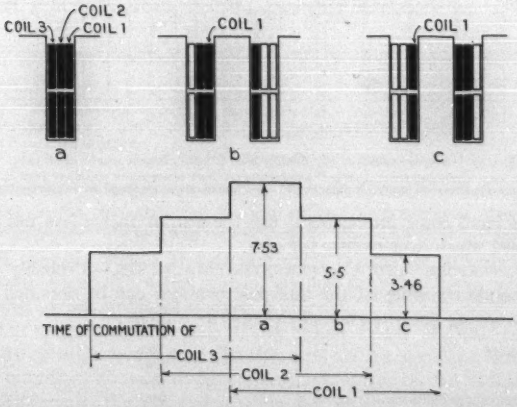
$$\phi_e = 2.54 \times .46\left(\log_{10}\frac{27}{4} - .2\right)$$

$$= 1.9$$

and $$RV_{av} = (2.4 \times 10^{-8})\ (2 \times 6.6 \times 16.5 + 1.9 \times 27)$$

$$= 6.1 + 1.43 = 7.53 \text{ volts.}$$

FIG. 15.



Stages in the commutation of a machine which has six conductors per slot, a full pitch winding and the brush width equal to the width of three commutator segments.

The brush, however, covers three segments, so that the flux linking each coil at the instant *a*, Fig. 15, will be three times as large as when only one segment is covered by the brush. The time of commutation, however, is also increased in the same ratio, so that at the instant *a* the reactance voltage of coil 1 is approximately

$$6.1 + 1.43 = 7.53 \text{ volts};$$

at instant *b* it is equal to

$$6.1 \times \tfrac{2}{3} + 1.43 = 5.5 \text{ volts};$$

and at instant *c* to

$$61 \times \tfrac{1}{3} + 1.43 = 3.46 \text{ volts.}$$

FIG. 16. FIG. 17.

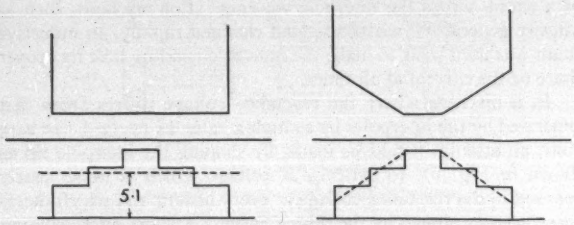


FIG. 16.—Commutation with a uniform air-gap under the interpole.
FIG. 17.—Improvement in commutation due to suitable shaping of the interpole tip.

If the air-gap under the interpole were uniform, as in Fig. 16, the voltage to be generated in each coil as it passed under the interpole would be 5.1 volts

and $5.1 = 2 \times L_i \times V_c \times B_g \times 10^{-8}$

where L_i = axial length of interpole = 15.5 inches.

V_c = peripheral velocity of armature in inches per second = 1420

so that

B_g = average interpole gap density = 11,500 lines per square inch.

Now, the ampère turns required to produce this flux density of 11,500 lines per square inch may be obtained from the formula

$$B_g = 3.2 \frac{\text{ampère turns}}{\text{effective air-gap in inches}}$$

And if the gap = 0.5 inch, then the ampère turns = 1800.
Thus we have

Armature ampère turns per pole	=	8,800
Interpole gap ampère turns	=	1,800
Ampère turns for interpole	=	10,600
	=	k (armature ampère turns per pole).

where k in this case is 1.2, and is seldom less than this value, so as to leave some working margin for adjustment of the interpole gap when the machine is installed.

A few years ago it was the practice to make the interpole ampère turns 40 per cent. greater than the armature ampère turns per pole, and then to adjust for sparkless commutation by means of a shunt across the interpole winding. For machines such as railway generators, where the load changed rapidly, an inductive shunt was used so as to make the interpole winding take its proper share of the current at all times.

In a machine where the reactance voltage differs from that generated by the interpoles by as high a value as $(7.53-5.1)=2.43$ volts, an attempt would be made, by shaping the interpole tip as shown in Fig. 17, to generate a voltage which is more nearly opposed to the reactance voltage at every instant and which therefore varies as shown by the dotted curve. A short pitch winding also would probably be used, so that the upper and lower layers of conductors in a slot would not be undergoing commutation simultaneously, and the reactance voltage would thereby be reduced.[9]

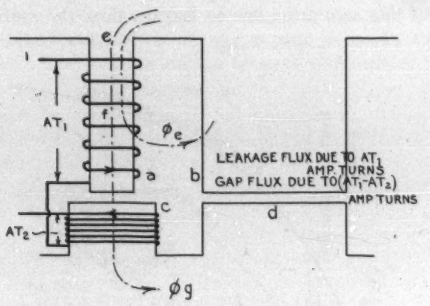
It is evident that in this particular machine, which is of rather high speed for the output, the reactance voltage has reached a value which cannot safely be exceeded, so that it would not be advisable to increase the slot depth in order to increase the value of q, the ampère conductors per inch of periphery. In case of slow-speed machines, on the other hand, the reactance voltage is low and interpoles are not really necessary. The value of q in such cases is limited more by heating than by commutation, because with the poor ventilation obtained in slow-speed units low current densities are required, and any large increase in the value of q over the values given in Fig. 14 would be accompanied by abnormally deep slots. The tendency, however, is towards higher

[9] "Effect of Brush Width on Commutation," by Lewis, *Electrical Journal*, vol. xviii, August, 1916 (p. 376).

speeds, now that the commutation limit has been raised by the use of interpoles.

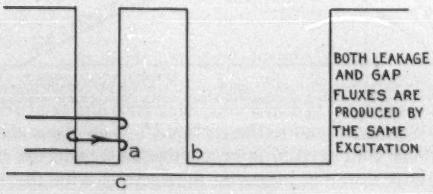
There is one limitation to be found in interpole machines which differs from anything we have in the non-interpole type.

FIG. 18.



Magneto-motive forces as found in interpole machines.

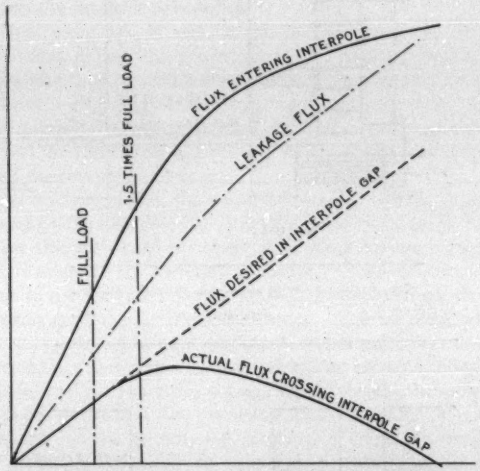
FIG. 19.



In compensated machines the only effective magneto-motive force that can cause interpole leakage is the small value due to the interpole excitation.

In Fig. 18, if AT_1 is 20 per cent. greater than AT_2, then the m.m.f. tending to send flux from *a* to *b* is five times as large as that tending to send flux from *a* to *c*, and, as the area of the leakage path *ab* is large compared with that of the main path *ac*, the leakage flux ϕ_e is large compared with the useful flux ϕ_u. This tends to cause saturation in the part *ef* of the flux path, even although the densities in the part *cde* of the path be low and, because of this saturation due to leakage flux, the useful flux is

FIG. 20.



Test curves showing the effect of interpole leakage on the value of the interpole gap flux.

not directly proportional to the current.[10] Now these are exactly the conditions that exist in interpole machines, and the curves in Fig. 20 show how the magnetic fluxes vary with the interpole current in an actual machine.

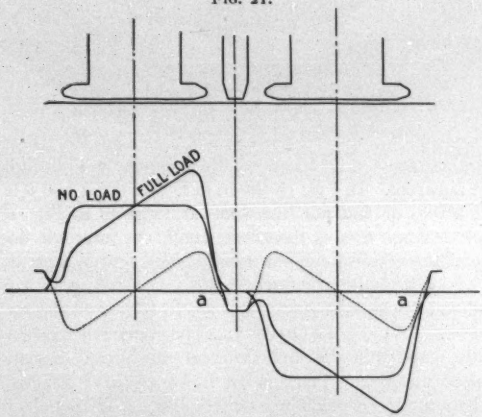
For good commutation over a wide range of load it is necessary that the field in the interpole gap increase directly with the armature current. If, for example, the reactance voltage at full

[10] "Commutating Poles," by Stokes, *Transactions of A. I. E. E.*, vol. xxxii, June, 1913 (p. 1540).

load is exactly balanced by the voltage due to the interpole field, then, as shown in Fig. 20, only 90 per cent. of the reactance voltage is balanced at 50 per cent. overload and commutation is impaired. To keep the interpole leakage down to a value that will not cause trouble it is necessary to limit the ratio of the ampère turns on the interpole to the length *ab*, Fig. 18, and this means the setting a limit to the value of *q*, the ampère conductors per inch of periphery.

One other feature of the design on page 31 is of considerable importance. The average voltage between commutator segments

FIG. 21.



Flux distribution in the air-gap of an interpole machine.

has the high value of 17.1 volts, and if the flux distribution curve in the air-gap at full load is as shown in Fig. 21, then the voltage between the segments of a coil located at *a* is about 30 volts and there is a tendency for the machine to flash over, which tendency becomes greater with increase of load. It has been shown that arcing between the segments of large machines is liable to start at about 30 volts,[11] so that the machine will not carry any overload unless armature reaction is so compensated as to prevent distortion of the field. This result is accomplished, as shown in

[11] "Physical Limitations in Direct-Current Commutating Machinery," Lamme, *Transactions of A. I. E. E.*, vol. xxxiv, September, 1915.

Fig. 22, by placing a winding on the pole face which has a number of ampère turns per pole equal and opposite to that of the armature winding. The interpole is still required to overcome the reactance voltage, but the number of ampère turns on the interpole need only be that required to produce the desired flux density, since the effect of armature reaction has been wiped out by the compensating winding. In the machine on page 31, for example, we found that

Armature ampère turns per pole	= 8800
Interpole gap ampère turns	= 1800
Ampère turns for the interpole	= 10,600

When a compensating winding is placed on this machine, however, we have:

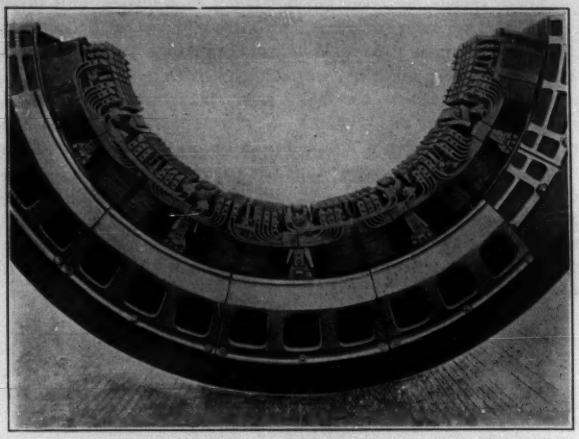
Armature ampère turns per pole	= 8800
Compensating ampère turns per pole	= 8800
Interpole gap ampère turns	= 1800
Ampère turns for the interpole	= 1800

Another great advantage of the compensated machine will now be apparent. In Fig. 19 the m.m.f. between *a* and *b* is equal to that across *ac* and not five times as large as in Fig. 18; the interpole leakage flux is therefore small, the interpole does not become saturated, and commutation is satisfactory over the wide range of load handled by such machines as rolling-mill motors and railway generators.

EFFECT OF SPEED ON OUTPUT.—The statement has been very generally made that the direct-current machine is essentially a slow-speed machine. The speeds, however, have gradually increased as interpole machines replaced those of the older type. Thus the 2750-kilowatt units of the Boston Elevated Company, installed in 1903, ran at 75 revolutions per minute, while the 3750-kilowatt units installed in Cleveland in 1911 had a speed of 180 revolutions per minute. In the case of motor-generator sets again, where there is no restriction to the speed except that the cost for a given output shall be a minimum, the development has been as follows:

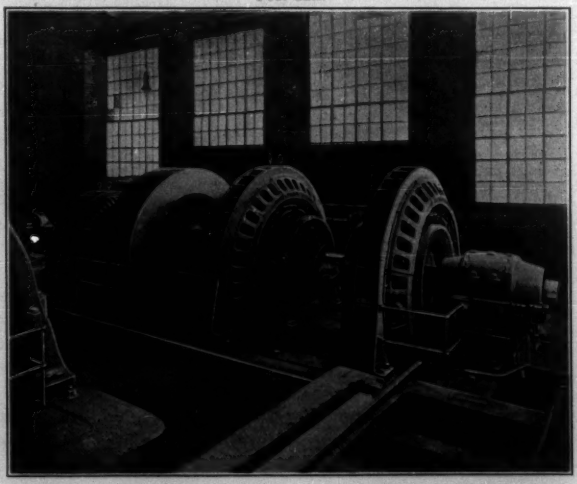
Date	Poles		Kilowatts	Volts	R.p.m.	Weight, pounds
1906	10	interpole	1000	600	514	33,000
1910	8	interpole	1000	600	750	24,000
1916	6	interpole and compensated	1000	600	900	19,000

FIG. 22.



Part of a flywheel motor generator set under construction, showing interpole and compensating windings.

FIG. 22A.



Flywheel motor generator set of which the above machine is a part. This set was installed by the Algoma Steel Company to feed two reversing rolling mill motors.

These speeds, however, do not begin to compare with those found in alternator practice; turbo machines of 6500 kv.a. capacity now run at 3600 revolutions per minute. To find wherein the direct-current machine is limited, let us take a good type of non-interpole machine, gradually raise the speed, and see what limits are encountered. Column 1, Table II, gives data on such a machine. If the speed is doubled, so also are the voltage and the output; also the reactance voltage has passed a safe value and interpoles become necessary. At three times normal speed the average voltage between segments has become so large that compensating windings are required, nor can the speed be increased much further without danger of flashover, even although the armature is compensated.

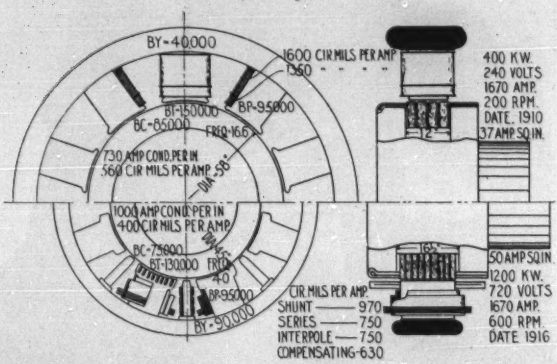
TABLE II.

	1	2	3	4
Kilowatts	400	800	1200	1200
Volts	240	480	720	720
Ampères	1670	1670	1670	1670
Revolutions per minute	200	400	600	600
Slots per pole	20 (.43″x 1.6″)	....	....	14 (.54″x 1.5″)
Conductors per slot	4 (.14″x .85″)	....	....	6 (.12″x .55″)
Tooth/slot	1.11	Smaller than necessary		1.33
B_t lines/square inches	150000	....	Too high	130000
B_e lines/square inches	83000	....	Too high	75000
Frequency	16.6	33.3	50	50
Armature A. T. per pole	6700	....	....	8800
Ampère turns (gap and tooth)	8280	Larger than necessary		6000
Ratio	1.23	....	....	0.68
Gap clearance	0.3	Larger than necessary		....
Reactance voltage	1.6	3.2 needinterpoles	4.8 need interpoles	7.53
Average volts per segment	6.0	12.0	18.0 need compensating wind.	17.2
Peripheral velocity, armature	3040	6080	9120	6600
commutator	1830	3660	5490	4200
Ampère conductors per inch (armature)	730	Smaller than necessary		1000
Ampère square inch, armature conductor	2250	Smaller than necessary		3200
Ampère square inch, brush contact	37	Smaller than necessary		50
Volts drop per pair brushes	2.5	Larger than necessary		2.0

It is true that the machine would be somewhat modified because of the high speed; thus the teeth would be wider to reduce the flux density, also the current density would be increased because of the better ventilation, but these facts do not materially change our conclusions. The actual design, given in column 4, is drawn for comparison in Fig. 23 alongside of the original 200-r.p.m. design, and shows very clearly complications that have been made necessary by high speeds. This complication may also be seen by a comparison between Figs. 24 and 25.

It would appear, then, that there is a limit to the capacity of

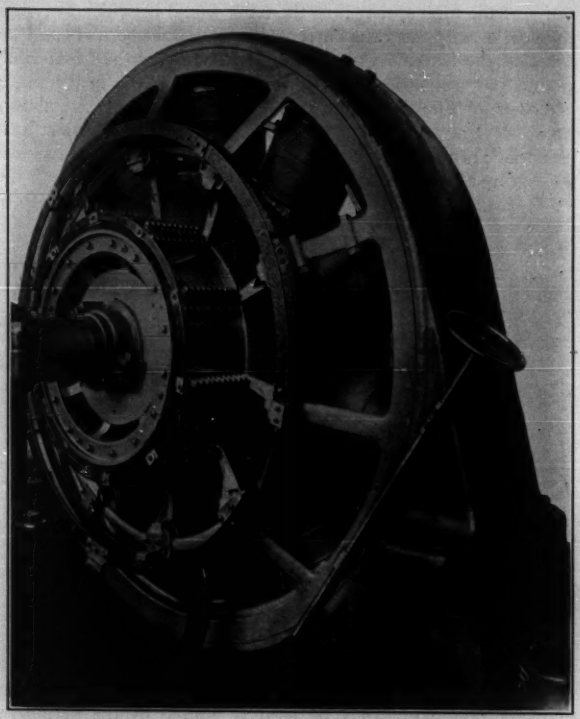
FIG. 23.



Comparison between a slow-speed and a high-speed machine with the same output per revolution.

the generator that can be built for a certain speed. If, for example, the revolutions per minute have been fixed, the maximum diameter that may safely be used is limited by the peripheral velocity. With the diameter thus fixed, the output of the machine is limited by the length of the armature core. As this element is increased in value the reactance voltage also increases, and finally interpoles become necessary for successful commutation. The core length may now be further increased, but a second limit is soon reached at which the voltage between two adjacent commutator segments becomes of such a value that the machine is liable to flash over. Let us therefore fix limits to the peripheral velocity of the armature, to the reactance voltage, and to the voltage be-

FIG. 24.



Engine type of generator without interpoles, date 1904.

tween adjacent commutator segments, and see what sort of an output equation can be built up that will embrace these quantities.

(*a*) *Non-interpole machines:*

$$\text{Watts} = \frac{B g^{\frac{1}{2}} q}{6.08 \times 10^{8}} (D^2 L) \text{rpm}.$$ (see page 29)

and $RV = 4 T^2 I_c \frac{\text{rpm}}{60} S(2 \times 10 \times L_e + 2L_e) 10^{-8}$ for a full pitch winding (see page 25).

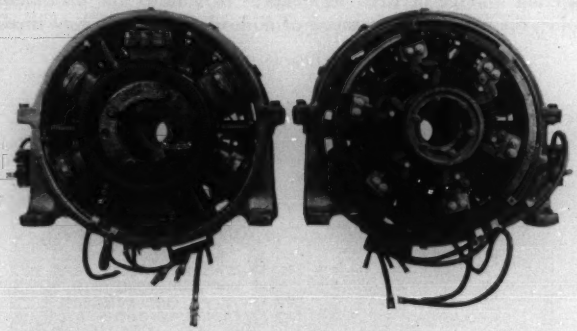
$= SI_cL \times \text{rpm} \times 10^{-8}$ approximately for a *short pitch* multiple winding with one turn per coil.

$$= \frac{\pi Dq}{2} \times L \times \text{rpm} \times 10^{-8}$$

$$\text{therefore watts} = \frac{B_g \dagger (RV)}{6.08} \times \frac{2}{\pi} \times D$$

$$= 0.4\, B_g\, (RV)\, V_a/\text{rpm}.$$

FIG. 25.



Engine type of generator with interpoles, date 1915.

If we take $B_g = 60{,}000$ lines per square inch (see Fig. 13).

$\dagger = 0.7$ (see Fig. 9).

$RV = 2.5$ (see page 25).

V_a = peripheral velocity of armature = 9000 feet per minute.

then the maximum output in kilowatts 380,000 r.p.m. which is the equation to the curve for non-interpole machines given in Fig. 26.

(*b*) *Interpole machines*

In this case the output is limited by the voltage between adjacent commutator segments and

$$\text{watts} = \frac{\text{volts per conductor} \times \text{current per conductor}}{\text{number of conductors}}$$

$$= \frac{E_s}{2} \times \pi Dq \text{ for a one turn multiple winding}$$

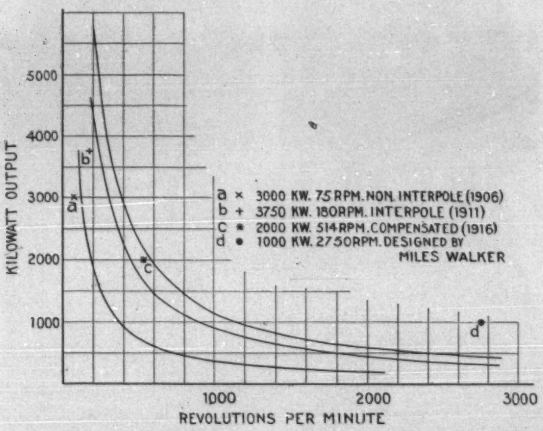
$$= \frac{E_s}{2} \times \frac{12\, V_a}{\text{rpm}} \times q$$

The voltage E_s between adjacent commutator segments must not be large enough to maintain any arc that may be started between the segments. Small machines have been operated successfully with a maximum value of 60 volts between segments, but

it has been found that in the case of machines of large output, where the resistance of that part of the winding between two segments is necessarily very low, it is not safe to operate with a maximum in excess of 30 volts between segments.

In Fig. 21 the no-load and also the full-load flux distribution curves are shown. From such curves it will be found that the average voltage between segments is 0.72 times the maximum when the machine is operating at no load, and is only 0.55 times

FIG. 26.



Maximum output of direct-current generators.

the maximum value when the field is distorted by the full-load current in the armature; this latter figure is for an average interpole machine in which the exciting ampère turns per pole for gap and teeth is about 0.8 times the armature ampère turns per pole at full load. If, then, the maximum voltage between segments is limited to 30 volts, the average voltage between segments should not exceed $0.55 \times 30 = 16.5$ volts, or even 15 volts if the machine is liable to be overloaded. If, however, a compensating winding is placed on the pole face, values as high as $0.72 \times 30 = 21.5$ volts may be used.

If we take

$V_a = 9000$ feet per minute;

$q = 1100$ ampère conductors per inch (see Fig. 14);

$E_s = 15$ for interpole machines;

$= 20$ for compensated machines;

then the maximum output in kilowatts = 900,000/rpm. (interpole) or 1,200,000/rpm. (compensated); and these are the equations to the curves for interpole and for compensated machines given in Fig. 26.

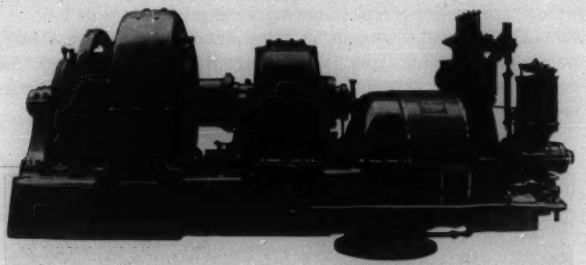
FIG. 27.

15,000-horsepower reversing rolling-mill motor of the two machine-type. Speed 0 to 120 r.p.m.

It must not be supposed that the values given by the three curves in Fig. 26 have not been exceeded. There are a number of non-interpole machines of 3000 kilowatts at 375 revolutions per minute in operation at the Illinois Steel Company, South Chicago, and yet the curves indicate that 125 revolutions per minute is about the limit in speed for machines of this output. They were built, however, with one segment per conductor instead of one segment per coil so as to reduce the reactance voltage to half value, this result being obtained by the use of connectors brought to the commutator from the back of the armature winding. Then

the Westinghouse Company has built a number of reversing mill motors rated at 15,000 horsepower at 120 revolutions per minute. These have been made possible by the adoption of a two-

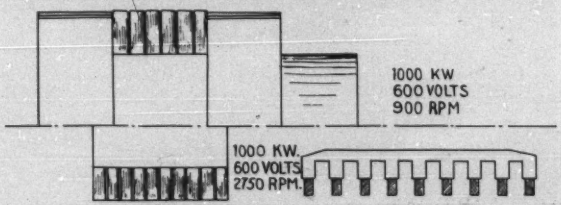
FIG. 28.



500-kilowatt geared turbo-generator with a speed reduction of 5000/900 r.p.m.

unit type, as shown in Fig. 27. Again, Miles Walker [12] has given data on a 1000-kilowatt turbine-driven machine which operates at 2750 revolutions per minute. This machine also has one seg-

FIG. 29.



Comparison between a geared and a direct-connected turbo-generator of the same output.

ment per conductor, and it has a compensating winding. The constants of interest are

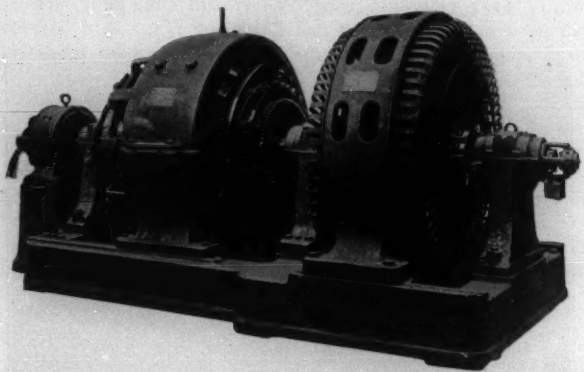
$E_s = 17$ volts between segments.
$q = 800$ ampère conductors per inch.
$V_a = 17{,}300$ feet per minute.

The machine, therefore, will operate successfully. It would appear, however, that British manufacturers have something to teach us about the construction of high-speed commutators, be-

[12] "Design and Specification of Dynamo Electric Machinery."

cause the commutator for this particular machine has nine shrink rings and a rubbing velocity of 10,000 feet per minute. Some development work on similar machines has been done in this country, but there has been little demand for the machine in large sizes, and it has been almost entirely superseded by geared units, such as that shown in Fig. 28, where the generator and the tur-

FIG. 30.



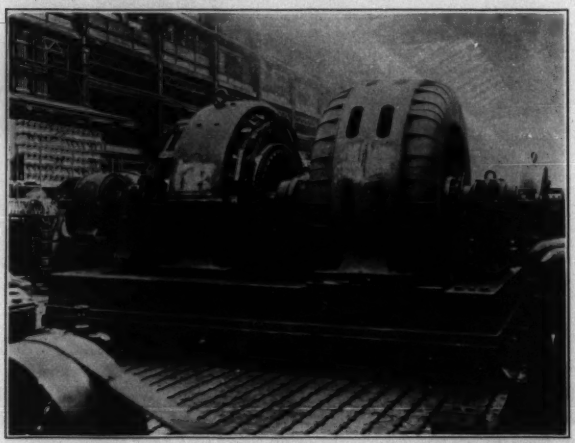
Motor generator set with compensated interpole direct-current generator. The construction of the compensating winding is of interest because it is of a double-layer, barrel type similar to that on the stator of an induction motor.

bine each runs at the speed for which it is best suited. The essential differences between the two types of machine are shown in Fig. 29. The important design constants are:

Kilowatts	1000	1000
Volts	600	600
Revolutions per minute	2750	900
Poles	4	6
Armature diameter in inches	24	36
Core length in inches	21	15
Maximum tooth density in lines per square inch	94,000	135,000
Core density in lines per square inch	68,000	85,000
Frequency in cycles per second	92	45
Armature surface velocity in feet per minute	17,300	8500
Commutator rubbing velocity in feet per minute	10,000	5000
Ampère conductors per inch	800	880
Circular mils per ampère	550	450
Average volts per segment	17	20

Interpoles and compensating windings had been suggested as early as 1886, but we find that as late as 1904 S. P. Thompson wrote as follows: [13] "It is an open question whether the employment of any of the more elaborate devices can come commercially into use except perhaps for machines of moderate output. An examination of the largest machines of the present day about which there can be no question as to the successful operation in-

FIG. 31.



Motor generator set with compensated interpole direct-current generator. The compensating winding is constructed similar to the well-known chain winding in alternators, and should be compared with the construction shown in Fig. 30.

variably shows that the heating limit is reached before the point at which sparking occurs." The development that has taken place during the last thirteen years can perhaps be appreciated when we find ourselves compelled to state that "There is no question but that without interpoles and compensating windings it would be impossible to build machines to carry the overloads, to operate at the high speeds and through the wide ranges of speed that are expected to-day by the operating engineer."

(To be continued.)

[13] "Dynamo Electric Machinery," vol. i, 1904 edition, p. 272.

RECLAIMING THE EVERGLADES OF FLORIDA.*

BY

ISHAM RANDOLPH, D.Eng.,

Member of the Institute

PONCE DE LEON discovered Florida, March 27, 1512. I discovered it in 1913; not that I had not previously seen on the map a flat, misshapen projection fending the Gulf of Mexico from the broad Atlantic. I had heard of St. Augustine and even of Tallahassee, but, apart from this casual hearing and seeing, the land of flowers was a *terra incognita* to me.

I was invited by Governor Park Tramel to come to Tallahassee to meet him and his fellow-members, Trustees of the Internal Improvement Fund of the State of Florida, to counsel with them about the drainage of the Everglades.

The name applied to that broad expanse of semi-aqueous land gave me no conception of its characteristics; those were to be revealed later.

When leaving Chicago, April 24, 1913, I equipped myself with the best map I could procure of the State with whose development I was so soon to be associated, and thereon was indicated a lake of considerable magnitude and named Okeechobee; a name conferred by the first inhabitants of a land in the State of Nature, but not then in the United States. Below this lake stretched an expanse almost coequal with the area of the lower peninsula, and on this was printed "Everglades." There were lines leading from the lake in a southeasterly direction, and these were labelled "canals," and they ended in natural channels leading to the Atlantic. They were sixty or seventy miles long, whereas the lake was only 25 miles away from an estuary.

When I met the Floridian powers that then were, on April 28, after a few preliminaries, I said to them that the whole subject was new to me and that, therefore, I might be "talking through my hat," but that, with the superficial knowledge I then had, I was led to believe that what was needed was a canal leading from the lake to the sea by the shortest possible route; and that locks

* Presented at the Stated Meeting of the Institute, held Wednesday, February 21, 1917.

should be put in the existing canals to prevent the lake water from flowing out over the Everglades.

Map of the Everglades.

To cut a long story short, I was engaged to organize a commission to report upon the problem and empowered to cause to be

made the necessary surveys and other investigations essential to a proper knowledge of the facts.

I associated with me two very able engineers. Mr. Marshall O. Leighton, who was for many years officially and most responsibly connected with the U. S. Geological Survey and was, and is, a recognized authority on hydrology and its collateral subjects. The other selection was Mr. Edmund T. Perkins, who had been responsibly connected with the engineering branch of the Department of the Interior. I assigned the hydrometric and meteorologic branch of the investigations to Mr. Leighton and the surveys to Mr. Perkins.

You may ask what I did; well, among other things, I, like the owl, did a "heap o' thinking."

We organized several survey parties and put them into the field, and it was a source of profound thankfulness that I did not have to follow them over the lines they run, for the hardships and discomforts which they endured were very great.

I was first to see the Everglades from the deck of the motor yacht *Pearl*, chartered for our use. On May 7 we passed through New River and into North New River Canal, headed for Lake Okeechobee, and it was not long after we entered that canal that my preconceived notions of the Everglades evaporated like morning mists. There was no growth of cypress and juniper, no tangle of vines, no contracted view, but a broad expanse of waterlogged land over which the eye searched in vain for a landmark, a distinguishing feature. There were no trees, no bushes, no mounds, nothing to steer towards nor to back sight upon. Just flatness grown up with saw grass: saw grass sometimes eight or nine feet high. Saw grass needs an introduction, a definition of its qualities. It is a broad-bladed grass, very stiff, and each edge of the blade is serrated like the teeth of a hack-saw, and its cutting qualities are almost as pronounced as those of its steel prototype. When an unfortunate has to forge his way through this growth, it is only a question of time, and not a long time at that, before his bootlegs or his leather or canvas leggings are scarified and torn away. I said there was nothing to steer by, but the navigator of a canal so narrow that turning his boat in it is a task of some difficulty has little need of compass or range target; his liquid path is narrow, if not always straight, and all he has to do is to shun the banks on either side.

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You may ask what I did; well, among other things, I, like the owl, did a "heap o' thinking."

We organized several survey parties and put them into the field, and it was a source of profound thankfulness that I did not have to follow them over the lines they run, for the hardships and discomforts which they endured were very great.

I was first to see the Everglades from the deck of the motor yacht *Pearl*, chartered for our use. On May 7 we passed through New River and into North New River Canal, headed for Lake Okeechobee, and it was not long after we entered that canal that my preconceived notions of the Everglades evaporated like morning mists. There was no growth of cypress and juniper, no tangle of vines, no contracted view, but a broad expanse of waterlogged land over which the eye searched in vain for a landmark, a distinguishing feature. There were no trees, no bushes, no mounds, nothing to steer towards nor to back sight upon. Just flatness grown up with saw grass: saw grass sometimes eight or nine feet high. Saw grass needs an introduction, a definition of its qualities. It is a broad-bladed grass, very stiff, and each edge of the blade is serrated like the teeth of a hack-saw, and its cutting qualities are almost as pronounced as those of its steel prototype. When an unfortunate has to forge his way through this growth, it is only a question of time, and not a long time at that, before his bootlegs or his leather or canvas leggings are scarified and torn away. I said there was nothing to steer by, but the navigator of a canal so narrow that turning his boat in it is a task of some difficulty has little need of compass or range target; his liquid path is narrow, if not always straight, and all he has to do is to shun the barks on either side.

You will realize the vastness of this Everglade expanse when told that it is equal in square miles to the combined area of Connecticut and Rhode Island.

The only relief to the monotony of such a voyage as we were taking was afforded by the abundant and beautiful bird life, ducks, herons, cranes, limpkins, and other aquatic fowl—met so casually that their family names, if ever heard, have been forgotten—were a constant delight to the eye. Then, too, there were the alligators, little and big, and the snakes and other reptile life.

On a later voyage, made pleasant for us by the presence of our

Taking a "Glade boat" to the Glades.

wives, they, the ladies, began counting alligators, but when they reached five score they tired of that census.

On the morning of May 8 we passed into Lake Okeechobee, the liquid heart of Florida, and on occasion that heart palpitates vigorously, as I was to realize to my discomfort at a later date when I was out on it in a storm. At the time of our first visit this lake had never been surveyed, and one of our duties was to determine its form and area. By an arrangement, which Mr. Leighton was able to perfect, this lake survey was made for us by Mr. E. P. Davis, Topographer of the U. S. Geological Survey. This survey was at our expense, but it is sponsored by the U. S. Geological Survey. The greatest width of the lake is, north and

south, 37 miles, and east and west, 31 miles; its area at elevation 19 above sea level is 725 square miles—which makes it the largest body of fresh water within the confines of any single state in the Union. It is a beautiful sheet of water, abounding with fish. So abundant are the finny tribes that the catch is an industry of great importance and its earnings run into six figures, and I am not sure that they do not call for seven. This catch was formerly shipped *via* the Caloosahatchie to Fort Myers and by the North New River Canal to Fort Lauderdale for shipment by rail to northern markets. But on the 6th of January, 1915, the track of the Florida East Coast Railway reached the north side of the lake and immediately a town sprang up, with the fishing industry as its inspiration. I was there early in November of that year and it then had 1100 inhabitants, a bank, electric light and ice plants, and other modern comforts and conveniences. Of course, the Florida East Coast Railway now takes all of "the catch" in its refrigerator cars and speeds it to northern markets. The harbor of this new town is on the Onoshohatchie Creek or River, which is a deep, crooked, and very picturesque stream. But the new town is on the north side of Lake Okeechobee, and, River, which is a deep, crooked, and very picturesque stream. ing from the lake southward to the Gulf; not bounded, however, by the Atlantic on the east and the Gulf of Mexico on the west, for there is on each side an inconsiderable uplift or ridge, and the Everglades fill the trough between these ridges. This uplift along the Atlantic coast is only a few miles wide, but much wider on the Gulf side.

What one sees of the Everglades is, as heretofore described, a vast expanse of saw-grass-covered, waterlogged soil. What one does not see is the solid substratum upon which this superimposed mass rests, and my ignorant preconceptions were first startled, then dissipated when I learned that the substratum is rock: rock whose general surface is level, but not smooth; it is full of pot-holes and minor indentations. How did this solid foundation for the peninsula come to be there? I do not know, but I accept with faith, not to be shaken until better proofs are forthcoming, the explanation given by Prof. Louis Agassiz in a report to the Superintendent of the Coast Survey, on examination of Florida reefs, keys, and coast, dated August, 1851. This

report is "H. Doc. 26," Appendix No. 10. I quote the introductory remarks:

"To form a correct idea of the Florida reefs, it is of paramount importance to keep in mind the topographical features of the whole country. The peninsula of Florida projects between the Gulf of Mexico and the Atlantic, from the 30th degree of northern latitude nearly to the 24th, as a broad, flat, low promontory, which has generally been considered a continuation of the lowlands of the Southern States. But, as we shall see hereafter, this is not the case, or, at least, not with respect to the southern extremity of the peninsula, which consists of the same formations as the reef itself. Again, in a physical point of

Hill's party *en route* for Lake Okeechobee.

view, Florida is not limited to those tracts of land, forming the peninsula, which rise above the level of the sea, for the extensive shoals along its southern extremity, between the mainland and the keys and reefs, as well as those extending to the west as far as the Tortugas, whence they stretch along the western coast, in fact belong to it, and are intimately connected with it, by their physical character. There is a similar tract of flats along the eastern shore, but it is not so extensive as on the southern and western shores, nor does it partake as largely of the peculiar character of the peninsula, being chiefly formed of the alluvial sand, drifted ashore by the waters of the Atlantic."

Agassiz credits the coral insect with this vast work of foundation building, as is shown by a further quotation:

"The reefs of Florida, as they have been described in the foregoing sketch of the topography of that state, and, indeed, the separate parts of each of these reefs, in their extensive range from northeast to southwest, present such varieties as will afford, when judiciously combined, a complete history of the whole process of their formation.

"Here we have groups of living corals, beginning to expand at considerable depth, and forming isolated, disconnected patches —the first rudiments, as it were, of an extensive new reef. There we have a continuous range of similar corals in unbroken continuity for miles, or even hundreds of miles, rising at unequal heights nearly to the surface.

"Here and there a few heads or large patches, or even extensive flats of corals, reach the level of low-water mark, and may occasionally be seen above the surface of the waters, when the sea is more agitated than by the simple action of the tides. In other places coral sands or loose fragments of corals, larger or smaller boulders, detached from lower parts of the living reef, are thrown upon its dying summits, and thus form the first accumulation of solid materials, rising permanently above low-water mark; collected sometimes in such quantities and at such heights as to remain dry, stretching their naked heads above high water.

"In other places these accumulations of loose, dead materials have entirely covered the once living corals, as far as the eye can reach into the depth of the ocean; no sign of life is left, except, perhaps, here and there an isolated bunch of some of those species of corals which naturally grow scattered, or of those other organisms which congregate around or upon coral reefs; but the increase of the reef by the natural growth of the reef-building corals is at an end. Again, in other places, by the further accumulation of such loose materials, and the peculiar mode of aggregation which results from the action of the sea upon them, and which will be more fully explained hereafter, extensive islands are formed, ranging in the direction of the mainland, which supports them. Elsewhere we may find the whole extent of the reef thus covered, which, after a still more protracted accumulation, perhaps becomes united with some continental shore.

"Now it must be obvious that, from a comparison of so many

separate stages of the growth of a coral reef, a correct insight may be obtained into the process of its formation; and, indeed, in thus alluding to the different localities which came under our own observation, we have already given a general history of its progress, which we now proceed to illustrate more in detail.

"We would, however, first remark that the extraordinary varieties which exist in the natural condition of different parts of the same reef, or of different reefs, when compared with each other, fully explain the discrepancies between the reports which have been obtained, respecting the reefs of Florida, prior to our investigations.

"It had been stated that the reefs consisted solely of living corals; and, indeed, this report is true of the outer reef, which is called by all the inhabitants of Florida 'the reef' *par excellence*, and is unfounded only with regard to those few islands which rise above the surface of the sea at Sand Key and the Sambos. Others, who had noticed only the larger accumulations of coral fragments which occur on the shores of some of the islands forming part of the Florida reef, had reported the islands to be formed of coral rocks; while some who had, perhaps, observed the extensive excavations made around Key West have told us only of the existence of oolitic and compact rocks, almost destitute of corals or other remains of animal life; and from still other localities comes the opinion that the rocks consist of nothing but more or less disintegrated shells, cemented together.

"Such are different species of Arca, the date-fish among the Mollusca, and many worms, especially Serpula among articulates, the agency of which in the formation of the keys will be described hereafter. All these animals and plants contribute, more or less, to augment the mass of solid materials which is accumulating upon the reef, and increase its size. Not only are the hard parts of shells, echinoderms, worms, or their broken fragments, heaped among the detritus of the corals, but occasionally even the bones of fishes and turtles, which are very numerous along the reef, may be found in the coral formations.

"The decaying soft parts of all these animals undoubtedly have their influence upon the chemical process, by which the limestone particles of their solid frame are cemented together, in the formation of compact rocks. Upon this point we may expect further information from Professor Horsford, who is now sub-

mitting to chemical analysis all the variety of rocks and the solid stems of the different corals obtained in Florida. Respecting the relations of the solid and soft parts of the living coral and their mode of growth, we would refer to a paper of ours now in press, to appear in the next volume of the 'Smithsonian Contributions to Knowledge.'"

Well, we know the rock is there, and the scientist quoted tells us how it came there.

It is overlaid with soil, the depth of which at Lake Okeechobee is from 14 to 20 feet, and this depth diminishes with the distance

"Flat Woods."

southward from the lake until at last the rock surface is visible and practically bare of soil.

This statement would lead the hearer to conclude that a barren region had been reached, but, far from it, the rock is so porous that roots penetrate it and find elements to support arboreal life. Some of the best-looking orange groves in Florida flourish in this rock land.

A pot-hole is made by the use of dynamite or other method of excavation. The stone removed is pounded up, mixed with any available soil placed back in the hole it came from, the tree set in

the spot thus prepared, and there it grows, thrives, and bears luscious fruit.

Mr. Kirk Monroe, author of many boys' books, said to me, "We farm here with pick and crowbar."

To get back to the work of our commission.

We put several parties in the field, and it would be interesting to follow the fortunes of each of these units, but to do so would far exceed the time limit which should be fixed for one evening's talk. So I will tell of the experiences of one party only—that in charge of Mr. George B. Hills. This survey was intended to develop a canal route from Lake Okeechobee through lowlands which would involve a minimum of excavation, and

Camp in the "Flat Woods."

it followed the depression known as Loxahatchie slough. For a little while wagons were available for transportation of camp equipage and provisions, but soon they were abandoned and resort was had to "glade boats," a light craft used by hunters and Seminole Indians. They, too, had to be abandoned, and then each man had a pack of provisions assigned him and they struck boldly into the swamp. Had I had the least conception of what these men were to endure, I should not have permitted the effort to be made. They struggled along through muck and saw grass, exposed to swarming insects and innumerable reptiles. Speak-

ing of reptiles, before they abandoned glade boats two of the men used a boat for a bunk one night. In the night they became aware of a third occupant, and that bed-fellow was a big snake. With alacrity they took to the swamp and left the bunk to the snake. I do not remember how many days they spent floundering through this morass, but at last they reached solid ground on the shore of the lake. They were out of food and so much exhausted that Mr. Hills told me they could not have struggled through another 1000 feet of such going as they had experienced. Their equipment and provisions had been sent to Fort Lauderdale, to be shipped aboard our chartered motor yacht to Lake Okeechobee. You can well appreciate the joy of these explorers when, after resting on the shore of the lake for about an hour, they saw the *Pearl* headed their way, laden with provisions, clean and whole clothes, cots, and other of life's comforts.

The journey over this route from the coast to the lake had never before been made by white men. I say by white men, for nobody knows where the Seminoles have been nor yet how they managed to traverse these wilds unscathed by saw grass and unbitten by reptiles. They go barelegged and barefooted. The Good Lord, " who tempers the wind to the shorn lamb," must have given these people armored hides.

This was the experience of one of our parties and was the hardest of all, but none of the others had reason to think they were out for a picnic. They did their work and did it well, and on the results we were able to make our report to the state authorities. This report is printed as Senate Doc. No. 379, 63d Congress, 2d Session.

In the main, the knowledge obtained confirmed the ideas which I advanced to the state authorities when I met them in Tallahassee, April 28, 1913.

To sum up our recommendations, as set forth in that report:

The vital suggestions were a canal from Lake Okeechobee to the St. Lucie River, about 25 miles long, 200 feet wide, 12 feet deep, to carry off the flood waters poured into the lake by the Kissimmee River and other northern tributaries.

To insure that the floods should take the route thus provided, we recommended that locks should be placed in each of the canals heretofore constructed, or hereafter to be constructed, leading from the lake, so as to prevent any flow of lake water through

those channels except what would be needed for purposes of navigation and irrigation.

The fall from Lake Okeechobee to the St. Lucie River, when the low lake stage is 16 feet above sea level (the high stage is 19 above sea level), is 15.2 feet. Allowing a slope of two-tenths per mile in the canal and taking the elevation of the St. Lucie River at the discharge end of the canal as +0.8, we have a head of 11 feet; we figured the minimum discharge through the canal as 5000 cubic feet per second, and the resulting electrical horse-power on 80 per cent. efficiency as 5000 net. Such a potentiality in a land where there is no coal and where firewood is scarce is an asset of very great value.

The value of these Everglades lands when drained is great beyond all question, but in my judgment they must be used to produce other things than semi-tropical fruits and garden truck. If this vast area was devoted to raising oranges, grape-fruit, and such other fruits as the soil is suited to, the yield would far surpass any human demand for it, and a glutted market would be an unprofitable one. But these lands will produce many of the staples, such as corn, broom corn, alfalfa, etc., and the meat supply can be greatly augmented by the cattle which may be raised in tremendous number in this land where there is no winter and where Nature offers a continual food supply for graminivorous animals.

The work that we recommended as desirable for progressive accomplishment would cost $22,400,000, but we recommended that the development should only proceed so fast as to keep ahead of actual demands of population.

The exploitation of the Everglades by land speculators has given a very unsavory reputation to these lands. I have never had occasion to know the facts in the case, but it has been given out as a fact that 40,000 persons had bought Everglades lands under promise that they would be drained and made fit for cultivation. The natural inference is that the retail venders of these subaqueous lands had wilfully and viciously misrepresented the facts in the case, and that they did greatly exaggerate the virtues of the soil they were selling is abundantly shown, but it is also a fact that men who bought large tracts from the state made the purchases under assurances from the state officials that the lands would be drained. These assurances were made by officials who

were ill advised and too optimistic. It was only after floundering along for years without adequate knowledge of the facts, the difficulties, and the proper remedies to be applied that the Governor and his associate trustees of the Internal Improvement Fund of the State of Florida decided to call into being "The Florida Everglades Engineering Commission." Nor do we who composed that commission claim to have exhausted the subject. This is brought out clearly on page 42, in this language: "Let no one vainly imagine that this report, or the report of any com-

Transitman and Leveller.
(Hendrickson) (Pynchon)

mission similarly instructed, can be the last word on the subject. On the contrary, such a report can only be the beginning of information. Patient and continuous study by the state's officers, and especially by the farmer, must proceed for a generation."

After deducting time lost in preparation for our work, and in assembling its results for the report, our investigations covered only four months.

One feature of the proposed Okeechobee-St. Lucie Canal is worthy of mention. That canal and Lake Okeechobee will furnish 57 miles of a 12-foot waterway across the state, leaving 62 miles of smaller canal, Lake Hickpochee, and the Caloosahatchie River to be improved to give a trans-Floridian barge canal from

the Atlantic to the Gulf of Mexico. The voyage around the end of the peninsula between the points connected by this barge canal (that is to be) is over 300 miles. To cover all of the points discussed in our report would be to reproduce the report, for therein we tried to elucidate the facts with the fewest words that would make them clear.

Before departing from the Everglades, I will reproduce some verses which I have seen in print describing somewhat poetically that vast expanse as seen by day and by night:

"THE EVERGLADES.

Across the widespread Everglades—
With its myriad host of saw grass blades,
And never a shrub, or vine, or tree,
To fix a spot on the grass-grown sea
That stretched away till the sea and sky
Seem'd to have met, to the far-strained eye—
The last slant rays of westering day
Had passed, with glow and glory, away;
And shades and shadows, mixed and blended,
Made the night of a day that is done and ended.
All overhead in the limitless blue
A sparkle of starlight filtered through
The mantle of circumambient air,
And naught could have made a night more fair,
Unless across the vasty dome
The crescent moon had deigned to roam.
Now we had journeyed all day long,
Hearing the engine's monotonous song,
While looking east or looking west,
The desolate scene our souls oppres't.
There was never the sign of a living thing,
Save life that throbs in the bird on the wing,
As we traversed a channel man had made
Across the widespread Everglade.
A channel through rock and muck and turf
To join a lake with old Ocean's surf,
And Okeechobee's waters flowed
Through the hollow way of this liquid road.
But all of a sudden, out of the dark,
There glowed and glimmered, spark after spark,
And all around, ahead and astern,
Countless lights began to burn.
Till it seemed, just then, to our dreamy gaze,
That the lights of a city began to blaze:

Lights in the windows of countless homes;
Lights that glowed 'neath palatial domes.
But the way those lights would flicker and wink
Filled us with wonder; just to think
Of the marvelous torches God supplies
To these tiny, light-winged fireflies.
But we thought beyond this fairy scene,
And saw a vision of what it will mean
To wrest for man this vast domain
Which for ages gone has tenantless lain,
Save for creatures that creep and crawl
O'er a surface held in water's thrall.
But we know, some day, that lights will show
Just where we saw the fireflies glow,
And that each of these lights will mark and tell
Of a home where comfort and love indwell,
And children will play in gardens of flowers,
And Florida say, 'This fair land is ours.'"

Tallahassee, Capital City—why mention that ancient town in connection with drainage? It is built on hills, its rains run off quickly, and, speaking aqueously, it is a dry town; how really wet it is I know not. But, be that as it may, Tallahassee is the seat of state government, and state government is inseparably connected with the Everglades. Without wise direction from that seat of power, the Everglades will never realize the poet's dream of many happy homes amid gardens of flowers. The powers centred in Tallahassee must set the stamp of their approval upon wisely-developed plans for the work, and they must secure the moneys necessary to carry out those plans upon a financial scheme which will so safeguard the purchasers of the state's securities that bonding houses will not look askance and shy away from such offerings.

But there is more of interest to Tallahassee than its Capitol. It is a picturesque old town; there are homes there generations old, with an air about them of the ancient régime, dignified ease and social consequence. There are wonderful live oaks in public squares and along shady streets with Spanish moss pendant from their giant arms. There are roses in Tallahassee, profuse in their bloom and delicious in their odor. It is a quiet old place in which one weary of the rush and bustle of life in our modern cities can find rest and time for reflection. One might almost call it a dead town. Once, when I was going there, a friend, who knew the

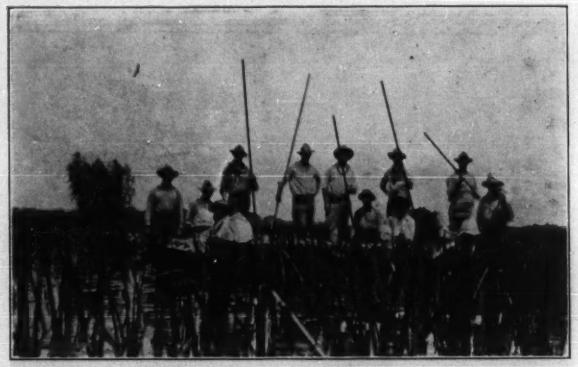
place better than I did, asked where I was going. I told him, "Tallahassee." "Well," he said, "when you get within ten miles of it your leg will go to sleep." The deadest place within the city limits is the old cemetery, an interesting "God's acre." The first settlers sleep quietly there. Among the tombs were many bearing my surname. The epitaph on one tomb thrills one, for it tells that the dust beneath was once the living son of Murat, Napoleon's great cavalry leader. The name on the tomb is Napoleon Achille Murat, Prince of Italy. He was born in Paris, 1801, the son of Murat and the great Napoleon's youngest sister, Caroline. When Murat was driven from the throne of Italy

A Seminole settlement.

this son was sent to Austria and there educated. When the power of his family was broken he came to America, purchased land in Florida, and became a planter; was mayor of Tallahassee. He married a daughter of Col. Byrd Willis, of Virginia. Many interesting stories are told as being characteristic of the man. He was very hospitable. It was his delight to have guests at meals. When his fortune was broken he could not overcome his hospitable instincts. It is said that on one occasion he brought home guests when the larder was empty. When he was advised of the facts he told the cook to go out to the pen, cut the ears off the pigs, and make a stew. I have heard that "One can not make a

silk purse out of a sow's ear," but never before have I heard of making a stew out of that organ. With this historic example in evidence, who shall say it can't be done?

In 1911, Senate Doc. No. 89, 62d Congress, First Session, was published. This contains a very interesting compilation of acts of Congress and of the state Legislature, and other papers, state and national, relating to the Everglades of Florida and their reclamation. This document contains a great deal of valuable information. If it is compared with the report contained in

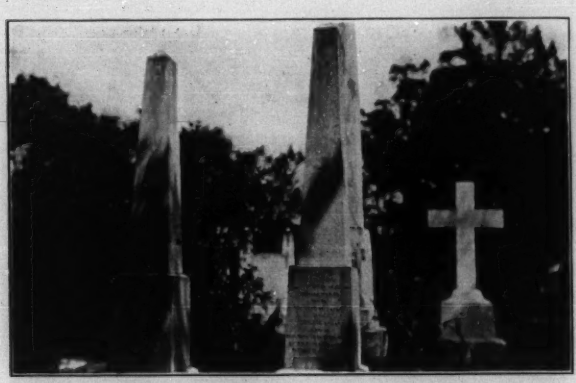


Working a passage on a "Glade boat."

Senate Doc. No. 379, 63d Congress, Second Session, a very radical contradiction of conclusions and engineering methods is immediately manifest. This Doc. No. 89 shows that by Act of Congress, approved September 28, 1850, upwards of 20,000,000 acres of land have been patented to Florida. It may interest Philadelphians to know that a former citizen, Mr. Hamilton Disston, bought 4,000,000 acres of these lands in 1881, and on February 26, 1881, the said Disston entered into contract to drain all of the overflowed lands in the state of Florida belonging to it, and lying south of Township 23 and east of Peace Creek. Under an amended contract, dated August 17, 1888, the Disston Company was to receive one acre of land for each 25 cents' worth of drainage work done under the contract. Following this contract

through to its final abandonment would be out of place here. The earliest work done under this contract was north of Lake Okeechobee, in the vicinity of Kissimmee. Kissimmee is located upon the north side of Lake Tohopekaliga, which is the head water of the Kissimmee River, and a beautiful sheet of water. In this lake are two lovely islands, one called Flemings Island, the other Paradise Island.

It was necessary that we—Messrs. Leighton, Perkins, and Randolph—should have a pretty good idea of the territory drained by the Kissimmee River, the run-off from which is dis-



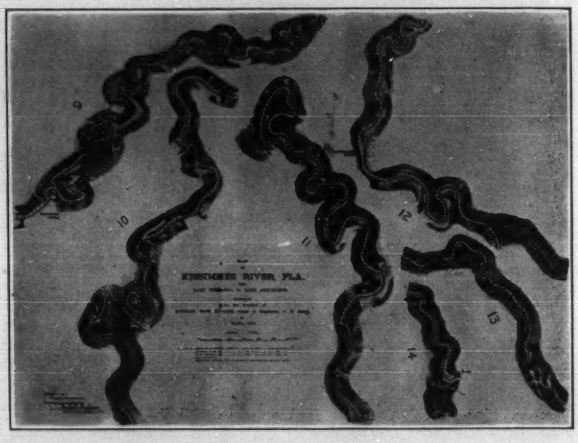
Tombs of Prince Napoleon Achille Murat and his Wife.

charged into Lake Okeechobee. To acquire this pretty good idea, we chartered the small steamer *Lilly*, owned and operated by Captain Clay Johnson, of Kissimmee. Captain Clay Johnson is one of the features of the Kissimmee region. If John Hay had known him he would have immortalized him in verse, or, had he been known to Mark Twain, one more character sketch would have found its place among the friends whose pen-pictures are in the great gallery delineated for us by that inimitable artist. A voyage with the Captain up or down that crooked river would serve to equip the voyager's memory with the lore of the land and the picturesque vocabulary of a voluble boatman.

We left that young city at 7:42 A.M., July 17, 1913, steamed

across Lake Tohopokaliga, eleven miles to the Southport Canal, dug under the Disston contract, and through this canal four miles into Lake Cypress, across it into Hatchenaha Canal, which led us into a lake of the same name, from which we issued into the Kissimmee River—a stream of many convolutions—as shown in the illustration below.

Well, it was an interesting and instructive voyage of 137 miles, ending in Lake Okeechobee at 3 P.M. of the second day. This voyage and a study of maps prepared by the War Department enable me to submit a report in December, 1913, showing

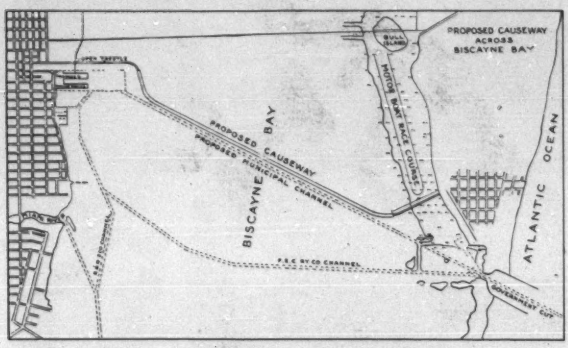


Characteristic windings of the Kissimmee River.

how this river can be shortened from 137 miles to 109 miles, made commercially navigable and at the same time drain a vast area of valuable land.

The parties who employed me to make this investigation and report were nearly mobbed by people who want these lands held in their present condition as cattle ranges. They do not own the lands, but they own herds of cattle and they need free pasturage to increase the profits of the business. I was told the owners of these lands had built fences about their holdings, but to no purpose, as the fences were cut down and the range kept open.

I cannot leave beautiful Lake Tohopokaliga without telling of a delightful episode in my experience. On Saturday, November 8, 1913, I visited Kissimmee to secure further data for the report which I had been employed to make. I hunted up Captain Clay Johnson and was able to add the desired information to my stock of knowledge. I went to the dock to see high-water marks, and, while thus engaged, a gentleman approached and introduced himself to me as Mr. Micklejohn and invited me to dine with him. He explained that he lived on the island, and invited me aboard his motor boat; there he introduced me to his wife; and soon another gentleman came aboard, who was introduced as Mr.

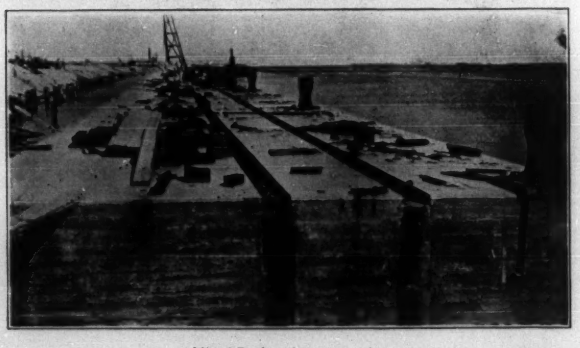


Map of Miami Harbor and Navigable Channel.

Frank Vans Agnew. The island was perhaps four miles from the dock, and our craft made its way through a choppy sea, beneath a threatening sky; we landed and reached a most attractive home just as the storm broke. It was a home with many comforts and no extravagances. To my surprise, it was electrically lighted by a little domestic electric light plant, operated by a 5-horsepower gasoline motor. I spent a charming evening, and the storm had abated and the moon come out when I said good-bye to Mrs. Micklejohn, and the gentlemen manned and cranked the motor boat and took me back to Kissimmee in time to catch the night train for Jacksonville. Mr. Vans Agnew made me the bearer to Mrs. Randolph of a basket of splendid island-grown fruit. Now, if the island is dwelt upon at all, strangers enjoy its pleasant

places, for Mr. and Mrs. Micklejohn, when the war broke out, went to the scene as Red Cross nurses; and Frank Vans Agnew added new dangers to a life of adventure. First, he enlisted in

Concrete piles used in Miami Dock.



Miami Dock under construction.

the cavalry, and, when he found how limited was its field of action, he got transferred to infantry and was put into the detachment of bomb-throwers and soon became chief bombardier of his

regiment. Is he alive to-day? I do not know, but I hope so. He wrote letters to his kindred in this country and in England, and

Hydraulic dredge *Florida*.

A "screw pine," Miami.

many of these were published in *Scribner's* as "Letters of a Bomb-thrower." He lived with the Cossacks on the Steppes of Siberia for five or six years. He was one of Roosevelt's Rough

Riders, and now he has seen real war, and I hope he may live through it and dwell once more on his beautiful island and enjoy the fruits of peace, even though the horrors and the thrills of combat shall never fade from his memory.

Well, I was to find that Florida had need of engineers for work other than drainage ditches and canals for navigation.

Miami wanted a harbor and an outlet to the sea, and, inasmuch as these wants had been felt for a long time and a paternal Government declined to satisfy them, Miami remembered that "the Lord helps those who help themselves," and the memory in

Some of the varieties of Florida fish.

spired the resolution to try a little self-help; but somebody had to plan the outlet to the sea and the dock, and I seemed to be the somebody who was needed, and I was instructed to go ahead. When the bonds were voted and said paternal Government saw that this young city by the sea was in earnest, it appropriated the funds necessary for deepening and widening the entrance to Biscayne Bay. The city's work, now nearing completion, comprises a channel three miles long, 100 feet wide, and 18.8 feet deep, a turning basin, a concrete dock 1000 feet long, of a design never before built. The reinforced concrete floor is carried on

bents spaced twelve feet centre to centre. There are five reinforced concrete piles in each bent, and on these is a massive reinforced concrete cap. I modestly assert that it is the finest dock on the Atlantic coast between Hampton Roads and Key West. Miami has had a wonderful growth; it is about 16 years old and it has a population of about 20,000. It is destined to rival Los Angeles.

Of course, the stupendous drainage project of Florida is that of the Everglades, but there are others of some consequence. The most important of these others is the Upper St. Johns River Drainage District, containing 262,000 acres. The work that it is proposed to do, however, will benefit about as many more acres. This project, upon which I reported in 1915, has been held up for over a year by the War Department, upon the plea that draining these marshes would injure navigation upon the St. Johns River. I have been able to convince the army engineers that this is an untenable theory, and nearly all of the arguments by which this change of view was brought about are based upon, and sustained by, facts in possession of the War Department and taken from records to which I was given access. Army engineers—at least those with whom I have come in contact—will not suppress facts which are within their keeping, although they may reach conclusions sometimes that are illogical. However, one of our human frailties is to think that he who differs with us is mistaken and wrong-headed. The permit for this work issued December 22 last, and we hope soon to make inapplicable the name "Ocean Prairie," which attaches to this tract.

In conclusion, let me advise all prospective purchasers of Florida lands to see what they propose buying, either with their own eyes or the eyes of a thoroughly reliable and experienced person delegated to act for them. Buying "a pig in a poke" is a safe venture compared with buying land "sight unseen"—be that land in Florida or in any higher latitude.

THE PHYSICAL BASIS OF COLOR-TECHNOLOGY

BY

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I. Spectral Analyses and Their Uses.

INTRODUCTION.

A PERUSAL of the literature on colored media and a general acquaintance with color industries have led to the conclusion that the chemistry of such substances greatly dominates the physics in color-technology. In fact, much of the physics of color is so little used in some of these activities that it is either not generally understood by color-technologists or its value is underestimated. Spectral analyses, the quantitative determinations of the spectral characteristics of colored materials, provide the foundations for many important aspects of color-technology, and without such data some work progresses more or less blindly. With such data, and those derived from less analytical methods, many interesting facts of color-technology can be bared and various factors can be determined which are unapproachable from the viewpoint of chemistry or from ordinary visual inspection. Having available a great deal of data resulting from the study of the physics of color and its applications, it appeared of interest to present some of the spectral analyses which might be helpful to others, and especially to point out some of the many uses of such data. This has been done in the following paper.

THE ANALYSIS OF COLOR.

Of the various methods of analyzing color, that of the spectrophotometer is the most analytical, and it provides data of far greater usefulness in the physics of color than the data which are yielded by any of the other methods. By this method the reflection (or transmission) factors of the coloring media are determined for radiant energy of all wave-lengths in the visible spectrum. When these are plotted we have the spectral

* Communicated by the Author.

reflection (or transmission) curves for the visible spectrum. By the same method the spectral character of an illuminant may be obtained. By multiplying the relative energy-values of the various wave-lengths of any illuminant by the corresponding visibilities of radiation, the special luminosity-distribution curves are obtained for the given illuminant. These latter will vary with the illuminant and are often of greater importance than the spectral energy-distribution curves from a visual viewpoint. It is obvious that by multiplying corresponding spectral values the spectral energy-distribution and luminosity-distribution curves of any colored medium may be readily obtained for any illuminant. Such data and their uses will be presented later.

The monochromatic colorimeter, which yields data in terms of hue, saturation, and brightness or luminosity, is the most generally analytical among the so-called colorimetric methods. This method analyzes color from the subjective viewpoint and yields data which may be readily visualized by one possessing some experience and an acquaintance with the spectral hues. From a subjective viewpoint the monochromatic colorimeter appears the most feasible method upon which to base a scientific nomenclature of color—an urgent need at present. An advantage of this method lies in relating the analyses to the constant and reproducible visible spectrum; however, in determining the saturation (unity minus the per cent. white) a white light is necessary, and this has not been standardized. A further difficulty lies in the unsettled state of color-photometry, which is necessarily involved in determining the luminosity or reflection and transmission factors. For these reasons at this time no data will be presented as obtained by this method which appears so promising.

The trichromatic colorimeter yields analyses in terms of three more or less arbitrarily chosen primary colors; namely, red, green, and blue. This is based on a well-known fact of color-mixture; *i.e.*, that any color may be matched in hue by a proper mixture of these three properly-chosen primaries. Young built what has later become known as the Young-Helmholz theory of color-vision chiefly upon facts of mixture of these three primaries. This method is not very analytical, and it is quite difficult to visualize a color from an analysis by this method. Furthermore, the data are often misleading to those not thor-

oughly familiar with their limitations, because the comparisons are made from the subjective standpoint.

Besides these chief methods, there are many kinds of colorimeters devised for special purposes—useful in their places, but yielding data of little general value analytically. Some of these are merely tintometers, consisting of a series of tints of various gradients in hue, saturation, and reflection (or transmission) factors, designed chiefly for special purposes, such as confining a given product within certain limits as judged by color.

Owing to the indefiniteness and limitations of the data yielded by most of these so-called colorimetric methods, and the difficulties attending the use of the monochromatic colorimeter at present, this paper will be confined almost entirely to spectrophotometric data and their uses. Many instances arise when the degree of absorption for ultraviolet and infra-red rays is of interest. The former can be determined readily by spectrophotography and the latter by means of such energy-measuring instruments as the bolometer or thermopile. Other methods are available, which may readily be ascertained if necessary.

COLORED MEDIA.

For the purpose of this paper three classes of colored media will be represented and discussed; namely, pigments, dyes, and vitrifiable colors or colored glasses. Pigments are distinguished from dyes by their insolubility in their vehicle, while dyes are soluble. This distinction may appear arbitrary, especially in some cases; however, it is employed to some extent and is a convenient classification. Pigments may be distinguished from paints in that the latter are pigments in a vehicle or medium. Vitrifiable colors are those which impart color to glass and to similar substances. Among pigments are found two general classes: one in which each particle is homogeneous, and the other in which a colorless base has been colored by depositing coloring matter upon it. Colored media vary in many physical characteristics, such as opacity, fineness, and refractive index, and they may be considered as varying in "coloring power." However, these facts are of interest only incidentally in this paper.

The color of a pigment in a finely-divided state, whether the particles are separated by air or by a vehicle, is due to innumerable selective reflections from, and transmissions through, the

minute particles. If the powdered pigment is given a smooth surface by pressure it does not appear as pure in color as when it is loosely packed, because in the latter case a greater proportion of the incident radiant energy is able to penetrate more deeply into the body and becomes colored by selective reflections and transmissions. Radiant energy is regularly reflected from even the small surfaces of the particles of pigment, and in those cases where the minute areas of surface are properly oriented this regularly reflected light does not find its way farther into the pigment, but is reflected practically unaltered in spectral character as compared to that energy which penetrates farther into the mass. Thus there is always reflected from pigments some radiant energy which is practically unchanged in spectral character, which accounts partly for the general lack of purity of the colors of pigments. It is seen that the character of the surface is important. Furthermore, the refractive indices of the pigment and of the vehicle (air in the case of dry powders) are of importance, because the amount of light regularly reflected from a surface is dependent upon these refractive indices. A careful study of the influence of the vehicle upon the color of a paint should lead to interesting data from this viewpoint alone. Work has been done in physical optics which is of extreme interest in this connection, but a discussion of it will not be presented here.

Although careful observation will reveal the influence of the porosity of a pigment surface upon its color, an excellent example for the purpose of illustration here is the color of a white cotton fabric compared with that of a white silk fabric after both have been soaked in the same dye-solution. In Fig. 1 are shown reproductions of microphotographs of white cotton and silk fabrics as photographed against a black background. It is seen that the silk is more transparent than the cotton fibres; in fact, the cotton fibres are merely translucent, as compared with the transparency of silk fibres. The latter permit the radiant energy to penetrate more deeply, in general, than the cotton fibres; in other words, the cotton fibres by diffuse reflection turn the energy backward before it has penetrated very deeply. For this reason the silk fabric appears of a purer color compared with that of the cotton fabric dyed in the same solution, the result, in the case of the silk, being similar to that which would have been obtained with the cotton if the latter had been dyed in a more concentrated solution of the dye.

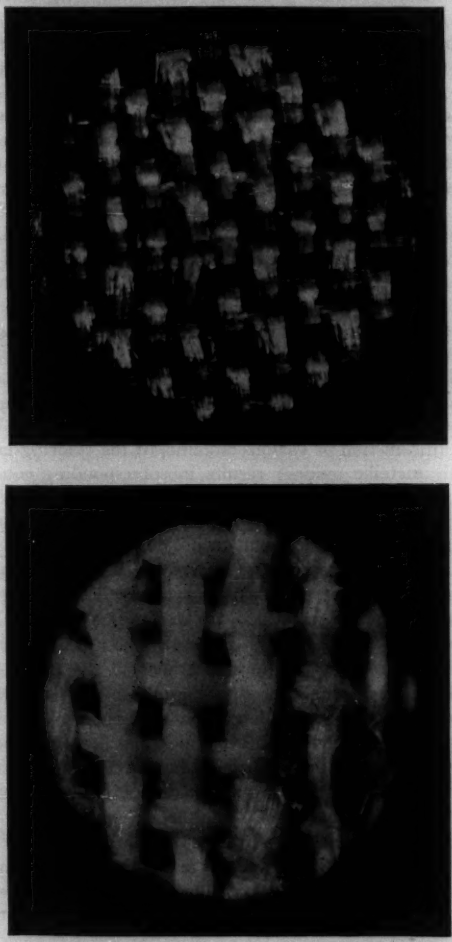


FIG. 1.

Cotton Silk

Microphotographs of cotton and silk fabrics against a black background.

In a manner similar to the case of pigments the solvent appears to have certain influences upon the color of a solution of a dye, although this subject has not been thoroughly studied. The substance upon which a dye has been deposited by immersion is also of importance in spectral analysis, as is indicated by the case of dyeing cotton and silk fibres, Fig. 1. The transmission factor of a dye-solution is a simple logarithmic function of the depth of a given solution or of its concentration, but this relation varies with the wave-length, in general in no definite relation between wave-length and spectral transmission factor. For this reason no simple relation between total transmission and depth or concentration can be established. Such values of total transmission must be determined by direct measurement or by integration, as will be discussed later.

Colored glasses can be treated much in the same manner as dye-solutions. A given concentration of coloring material in a glass (that is, a given colored glass) apparently obeys the same law relating to thickness and transmission factor for a given wave-length as a dye-solution. However, it is not established that the introduction of various amounts of the coloring material (generally metallic oxides) results in corresponding concentration, as would be true in the case of dyes. In glass there is more or less chemical action, and the uncertain conditions of melting make this point difficult to decide.

The physics of the process by which glasses are colored by means of metallic compounds is not wholly clear. There are many chemical analogies which are of interest for their parallelism to the colors imparted to glasses by the metals in different states, but the reasons for the appearance of the colors cannot be considered as being thoroughly established. Garnett[1] has presented a very interesting discussion of the colors exhibited by certain glasses in which metallic oxides had been incorporated. It is a common supposition that the colors of certain glasses, such as gold red glasses, are due to the presence of very minute particles of metal. Solutions of some metals exhibit colors which are often exhibited by colored glasses in which the same metals have been introduced. Siedentopf and Szigmondy, by powerfully illuminating specimens of colored glass and colored col-

[1] *Phil. Trans. of Roy. Soc.*, A, vol. 203, p. 385.

loidal solutions of metals obliquely, or at right-angles to the line of sight, were able to detect the presence of the metallic particles. Garnett's work explained some of their observations.

It is commonly considered that metals color glass in two ways: one by being in a state of true solution in the glass, and in the other by being in a colloidal state. An example of the former is copper blue-green glass, and of the latter, gold red glass.

In dealing with the physics of colored media from the viewpoint of the physicist one cannot avoid the conclusion that there is a wide application of physics to color-technology in many directions quite unexplored; however, such a discussion would be beyond the scope of this paper.

SPECTRAL ANALYSES OF PIGMENTS.

In presenting data which it is hoped will be of direct use to others only those colored media have been selected which are thought to be fairly constant in composition and representative. The spectral reflection factors of a group of dry powdered pigments,[2] commonly used in the paint industries and which from general observation appear representative, were determined by means of the spectrophotometer and the data are presented in Table I. The light was reflected from a thick layer of the powder, the surface being gently smoothed by means of a sheet of plane glass. Whites and blacks have been omitted, but these are by no means always neutral pigments. Whites are very commonly yellowish, and blacks (which are only approximately black, varying in reflection factor from 0.02 to 0.1) are often bluish or reddish. Although these departures from neutrality are not relatively great, they are sufficient to be detected by means of the spectrophotometer. Such small departures are readily detected by painting the inner surface of a box with such a supposedly neutral pigment and by viewing a white surface indirectly lighted by means of a light-source inside the box. The visible radiation suffers innumerable reflections [3] from the walls of the box, and that which illuminates the white surface is therefore much more colored than the pigment would appear under direct illumination. The spectral reflection factors of pigments are more difficult to obtain than the transmission factors of dyes in solu-

[2] Kindly furnished by Sherwin-Williams Company.

[3] M. Luckiesh, *Trans. I. E. S.*, **8**, 1913, p. 61.

TABLE I.

Spectral Reflection Factors of Dry Powdered Pigments.

REFLECTION FACTORS FOR VARIOUS WAVE-LENGTHS.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
American vermilion	0.08	.06	.05	.05	.06	.06	.09	.11	.24	.39	.53	.61	.66	.65
Venetian red	.05	0.5	0.5	0.5	.05	0.6	0.7	.12	.19	.24	.28	.30	.32	.32
Tuscan red	.07	.07	.07	.08	.08	.08	.08	.12	.16	.18	.20	.22	.23	.24
Indian red	.08	.07	.07	.07	.07	.07	.07	.11	.15	.18	.20	.22	.23	.24
Burnt sienna	.04	.04	.04	.04	.05	.06	.09	.14	.18	.20	.21	.23	.24	.25
Raw sienna	.12	.13	.13	.13	.18	.26	.35	.43	.46	.46	.45	.44	.45	.43
Golden ochre	.22	.22	.23	.27	.40	.53	.63	.71	.75	.74	.73	.73	.73	.72
Chrome yellow ochre	.08	.09	.07	.07	.10	.19	.30	.46	.60	.62	.66	.82	.81	.80
Yellow ochre	.20	.20	.21	.24	.32	.42	.53	.63	.64	.61	.60	.59	.59	.59
Chrome yellow (medium)	.05	.05	.06	.08	.18	.48	.66	.75	.78	.79	.81	.81	.81	.81
Chrome yellow (light)	.13	.13	.18	.30	.56	.82	.88	.89	.90	.89	.88	.87	.85	.84
Chrome green (light)	.10	.10	.14	.23	.26	.23	.20	.17	.14	.11	.09	.08	.07	.06
Chrome green (medium)	.07	.07	.10	.21	.21	.17	.13	.11	.09	.07	.06	.06	.06	.05
Cobalt blue	.59	.58	.49	.35	.23	.15	.11	.10	.10	.10	.11	.15	.20	.25
Ultramarine blue	.67	.54	.38	.21	.10	.06	.04	.03	.03	.04	.05	.07	.10	.17

tion, because in the former case more or less energy is regularly reflected from the particles directly into the instrument. Care must be taken to avoid placing the pigment surface in such a position with respect to the slit of the instrument and to the light-source that an undue amount of regularly reflected visible radiation enters the instrument. The visible radiation which is thus regularly reflected is practically unchanged in spectral character as compared with that which penetrates into the interstices of the pigment, and is colored by innumerable transmissions through, and reflections from, the minute particles of pigment. At any angle some of the energy is regularly reflected from the minute portions of the surfaces of the particles which are properly oriented. This accounts partly for the general lack of purity of the colors of "opaque" pigments. The data of Table I are plotted in Figs. 2 and 3.

Spectral analyses in the ultraviolet and infra-red regions are often of interest in general color-technology. In the former case spectrophotography is the simplest method of attack, although the procedure is a tedious one if high accuracy is desired. It is necessary to establish photographic-density and pigment-illumination (or exposure) relations for various wave-lengths in order to obtain the reflection factors for radiant energy of various wave-lengths. Besides this, the ordinary precautions of photographic procedure must be taken. Another possible method is that which involves the use of the photo-electric cell. No systematic data on pigments in the ultraviolet region have been obtained, so none will be presented, although ofttimes it has been necessary to investigate this region for a particular pigment. It is well to recognize the importance of such analyses in cases involving ultraviolet light. An excellent example is zinc white, which absorbs ultraviolet energy quite freely.

The investigation of the infra-red region requires a more elaborate apparatus, although in many cases where total energy-absorption is of interest this can be obtained rather easily by means of the thermopile or bolometer. In fact, the ordinary radiometer, or even the thermometer covered with a pigment, yields data which have some uses in practice. Coblentz[4] has published interesting data on the reflection factors of various sub-

[4] *Bulletin Bureau of Standards*, vol. 9, p. 283.

stances for infra-red and visible radiation of several wave-lengths. Among the substances which he studied were a number of pigments. The reflection factors of white pigments for energy of wave-length 4.4μ varied from about 0.1 to 0.4, and at 8.8μ and 24μ were considerably lower. These data especially emphasize the localized nature of absorption bands, as, for example, cobalt oxide is a better reflector of long-wave energy than zinc oxide, yet for visible rays it possesses an extremely lower reflection factor than zinc oxide. Lead oxide is a much more efficient reflector of long-wave energy than zinc oxide, magnesium carbonate, and other white pigments. The importance of the infra-red analyses is apparent in many practical activities. Coblentz has pointed out that a pigment which has a low reflection factor for energy of wave-lengths in the region of 8μ to 9μ is a better house paint in hot climes, because it re-radiates maximally in this region where the maximum radiation from bodies of temperatures from 20° to 25° C. is found. If the paint has a high reflection factor for visible rays it thus minimizes the heating effect of the incident energy. Such a combination is quite desirable in minimizing the heating effect of solar rays. This is merely one example of a vast number of interesting problems which could be met with more intelligence if spectral analyses were available.

SOME APPLICATIONS OF SPECTRAL ANALYSES OF PIGMENTS.

The chief use of the data derived from such spectral analyses is that of establishing the spectral character of the pigment. The general value of such data needs no defence, for it is the actual foundation of the pigment as a coloring material. Its purity is thus established; its influence in color-mixture may be predicted; the purity or desirability of a color resulting from various mixtures of pigments whose spectral analyses are available may be predetermined; and in many ways such data are useful. It is quite beyond the scope of a single paper to discuss all the physical uses of such data; besides, it is the intention to confine the discussion chiefly to aspects which are likely to be less commonly appreciated. For the latter purposes other data, such as the spectral energy-distribution in illuminants and the visibility of radiation of various wave-lengths, are necessary, therefore Table II is presented. The relative energy-values at various wave-lengths are given for four illuminants which represent nearly the

extremes commonly encountered from the viewpoint of color. In the last column are presented Nutting's visibility data. There is no general agreement as yet among investigators regarding the visibility of radiation of different wave-lengths; however, the

TABLE II.

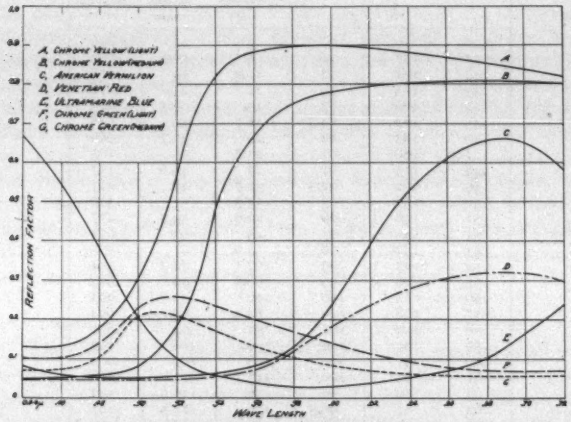
Spectral Energy-Distribution in Common Illuminants and the Visibility of Radiation.

Wave-length	Blue sky	Noon sun	Tungsten (vacuum) incandescent lamp 7.9 lumens/watt	Tungsten (gas-filled) incandescent lamp 22 lumens/watt	Visibility of radiation (Nutting)
0.40μ	170	67	9	15	.002
.41	177	72	9.5	16.5	.003
.42	181	75	10.5	19	.008
.43	185	79	12	23	.012
.44	186	83	15	26.5	.023
.45	187	84.3	16.7	30	.038
.46	185	88	20	33.7	.066
.47	180	91	23.5	38	.105
.48	173	92	27	42.6	.157
.49	162	92.5	32.7	47	.227
.50	157	95	37.5	52	.330
.51	146	96	42.6	56.5	.477
.52	140	97	49	62	.671
.53	132	98	54.9	67	.835
.54	127	99	62.1	72.5	.944
.55	120	99	68.6	78	.995
.56	115	100	76	83	.993
.57	108	100	83.4	88	.944
.58	104	101	91	94	.851
.59	100	100	100	100	.735
.60	97	100	108	105	.605
.61	93	100	117	111	.468
.62	90	99	126	116	.342
.63	87	98.5	136	121.5	.247
.64	85	98	146	126	.151
.65	82	97.1	157	131	.094
.66	80	96	167	135	.051
.67	77	95.5	179	140	.028
.68	76	94	189	143	.012
.69	72.5	93.5	202	147.5	.007
.70	71	91.7	212	151	.002
.71	69.6	90	223	153.5	.....
.72	68	88	235	156	.....

data of Nutting are sufficiently well established for the present purpose. His data were obtained by comparing the luminosity-values of known amounts of radiant energy with a standard source of luminous intensity by means of the flicker photometer. The values of luminosity were then reduced to a uniform or equal-

energy basis and are then termed visibilities. On multiplying each ordinate of a spectral energy-distribution curve of an illuminant, pigment, dye, etc., by the corresponding value of visibility the resultant data yield the spectral luminosity-distribution of the illuminant, pigment, dye, etc. Thus from the spectral energy and visibility data the relative spectral luminosity-values can be determined. On integrating the areas of the spectral luminosity curves the relative total luminosity-values of colored media and of illuminants can be obtained, and by dividing the area of one

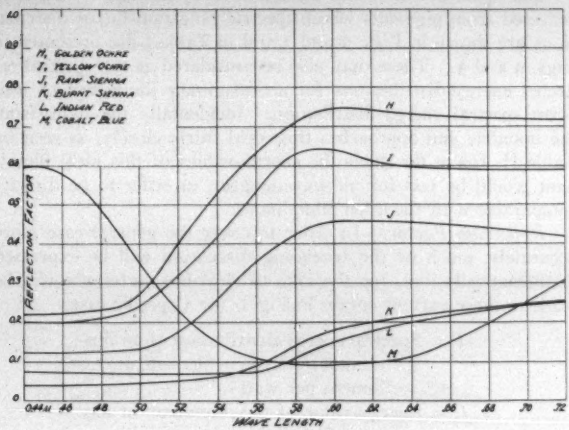
FIG. 2.



Spectral reflection-factors of pigments.

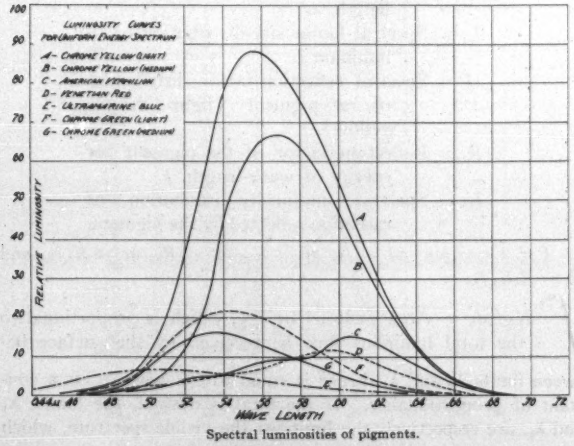
of the former by the area of one of the latter the reflection factor of the particular colored medium is obtained for the particular illuminant. Thus by computation the reflection factors of colored media can be obtained without any of the difficulties and uncertainties of color-photometry, for these have been involved in the determination of the visibility data. Such computations are found to yield results quite in agreement with those obtained by direct measurements of reflection (or transmission) factor. In fact, this method appeals very strongly to the author, especially because the spectral analyses should be available for many other reasons, so that reflection and transmission factors would be by-products.

FIG. 3.



Spectral reflection-factors of pigments.

FIG. 4.



Spectral luminosities of pigments.

The spectral luminosity-distributions of the visible radiation reflected from pigments whose spectral reflection-factor distributions are shown in Figs. 2 and 3 and in Table I are presented in Figs. 4 and 5. These may also be considered as the spectral reflected energy-distributions for an imaginary illuminant of uniform spectral energy-distribution. Incidentally the light from the noonday sun approaches this ideal fairly closely, as seen by Table II, for in this table the energy-values of this ideal illuminant would be 100 for all wave-lengths, in order to be directly comparable with the other illuminants.

Reflection Factor.—In order to cover the general case more accurately, much of the foregoing discussion will be expressed mathematically, but, for the sake of clearness, reference will be made to these various curves in Fig. 6 for a specific case.

I = Spectral energy-distribution of an illuminant (tungsten filament at 7.9 lumens per watt).

J_λ = Energy-value of the illuminant at any wave-length, λ.

V = Visibility curve (Nutting's data).

K_λ = Visibility-value for energy of wave-length, λ.

L_I = Spectral luminosity-distribution of illuminant I.

P = Spectral reflection-factor distribution of a pigment (light chrome yellow).

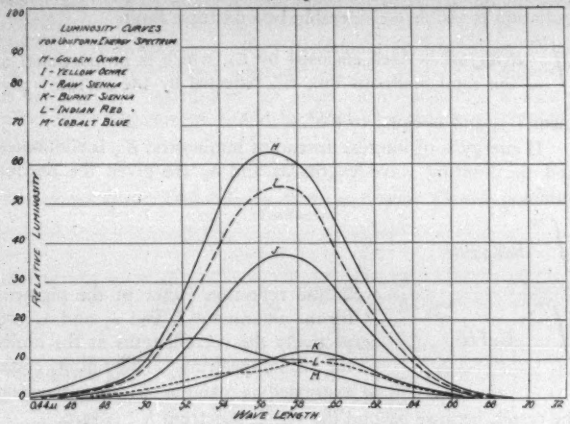
R_λ = Reflection factor of the pigment for energy of wave-length, λ.

L_P = Spectral luminosity-distribution of radiation reflected by the pigment.

For $\lambda = 0.52\mu$, $ad = J_\lambda$, $af = K_\lambda$, $ae = R_\lambda$, $ac = K_\lambda J_\lambda$, and $ab = R_\lambda K_\lambda J_\lambda$.

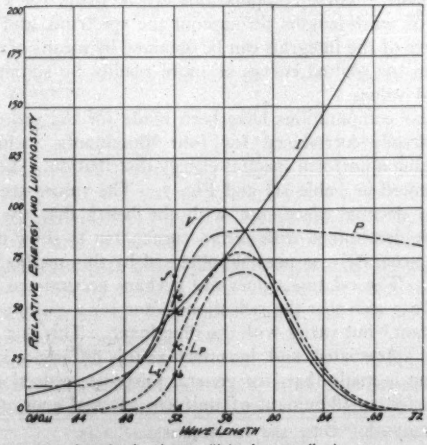
$\int_{\lambda_1}^{\lambda_2} K_\lambda J_\lambda d_\lambda$ = Area enclosed by L_I, which is proportional to the total luminous flux E, received by the surface between limits λ_1 and λ_2, hence is equal to CE where C is a constant of proportionality. If the total is desired, the limits, λ_1 and λ_2, are respectively the limits of the visible spectrum, which

FIG. 5.



Spectral luminosities of pigments.

FIG. 6.



A study of a pigment (light chrome yellow).

for most practical cases may be taken as 0.4μ and 0.7μ, although radiation is visible considerably beyond these limits.

$\int_{\lambda_1}^{\lambda_2} R_\lambda K_\lambda J_\lambda d\lambda$ = Area enclosed by L_p, which is proportional to the total luminous flux E', reflected by the surface (pigment P), and is equal to CE'.

If energy is of interest instead of luminosity, K_λ is eliminated and the limiting wave-lengths λ_1 and λ_2 are given the desired values.

$$\frac{\int_{\lambda_1}^{\lambda_2} R_\lambda K_\lambda J_\lambda d\lambda}{\int_{\lambda_1}^{\lambda_2} K_\lambda J d_\lambda \lambda} = \frac{E'}{E} = R =$$ the reflection factor of the pigment P for the illuminant I, and λ_1 and λ_2 are respectively the wave-lengths at the limits of the visible spectrum. These limits could be expressed as o and ∞ without changing the result, because beyond the visible spectrum K_λ is zero.

Many useful data can be obtained by such computations when the spectral energy-distributions of pigments and of illuminants are available. These computations can be made for a sufficient number of wave-lengths throughout the spectrum, and the relative values of the integrals can be obtained by means of a planimeter from the plotted curves or more readily by summating the computed values.

Similar computations have been made for the group of pigments already introduced for four illuminants, including the ideal having a uniform spectral energy-distribution. These values are presented in Table III and Fig. 7. The values are given to the third decimal place, not with the belief that the absolute values are determined with such accuracy, but to show the differences as accurately as possible obtained by this method of computation. The relative values are perhaps accurate to the third place. It is seen that the reflection factor for a given pigment is not constant,[5] but varies with the illuminant. This is a point not generally appreciated, and, inasmuch as this difference exists, the suggestion is made that, for general purposes, reflection factors be given for an illuminant of uniform spectral energy-distribu-

[5] M. Luckiesh, "Color and Its Applications," 1915.

tion. In cases of direct measurement of these factors the clear noonday sun sufficiently approaches the ideal, as will be shown shortly. In cases where other illuminants are used these should be specified. For direct measurement the Nutting reflectometer is an excellent instrument for most cases, although a flicker-photometer attachment would be helpful in the case of colored pigments.

TABLE III.

Absolute and Relative Total Reflection Factors of Powdered Pigments for Various Illuminants.

	Absolute				Relative			
	Uniform energy-spectrum	Noon sun	Blue sky	Tungsten filament $7.9\frac{\text{lumens}}{\text{watt}}$	Uniform energy spectrum	Noon sun	Blue sky	Tungsten filament $7.9\frac{\text{lumens}}{\text{watt}}$
American vermilion	0.137	0.137	0.117	0.117	1.00	0.99	0.86	1.29
Venetian red	.106	.106	.095	.131	1.00	1.00	.90	1.23
Tuscan red	.107	.107	.101	.12	1.00	1.00	.95	1.12
Indian red	.099	.099	.092	.112	1.00	1.00	.93	1.13
Burnt sienna	.105	.106	.093	.127	1.00	1.01	.89	1.19
Raw sienna	.324	.326	.303	.366	1.00	1.01	.94	1.13
Golden ochre	.578	.581	.548	.634	1.00	1.01	.96	1.10
Chrome yellow ochre	.328	.33	.289	.404	1.00	1.00	.91	1.24
Yellow ochre	.486	.488	.46	.534	1.00	1.01	.95	1.11
Chrome yellow (medium)	.542	.545	.496	.63	1.00	1.01	.92	1.16
Chrome yellow (light)	.76	.765	.70	.82	1.00	1.01	.92	1.08
Chrome green (light)	.19	.194	.19	.175	1.00	1.00	1.03	.93
Chrome green (medium)	.136	.136	.142	.12	1.00	1.00	1.05	.88
Cobalt blue	.166	.162	.183	.13	1.00	.98	1.10	.79
Ultramarine blue	.08	.074	.095	.057	1.00	.93	1.19	.71

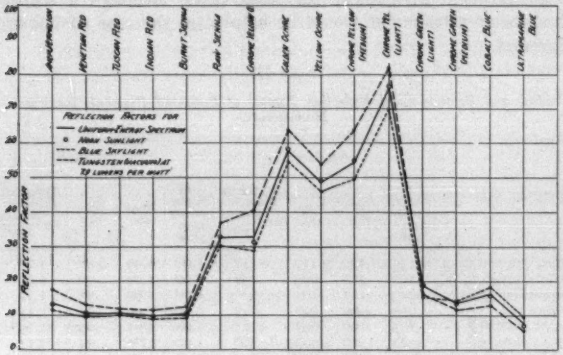
The measurement of reflection factor directly is by no means standardized, and in the case of colored pigments this measurement is attended with many difficulties, such as the distribution of luminous flux upon the surface, its angular position with respect to the photometer, color-photometry, etc. A discussion of this has been presented elsewhere.[6]

In Table III the relative reflection factors of each pigment by itself for the four illuminants are presented, that for the uniform energy-spectrum being taken as unity. This gives a better idea

[6] M. Luckiesh, *Electrical World*, May 19, 1917.

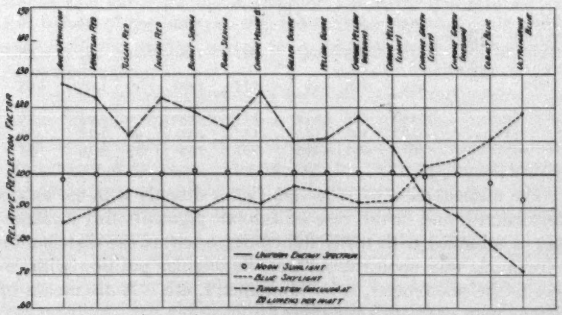
of the magnitude of the variation of the reflection factor with the spectral character of the illuminant. These values are plotted in Fig. 8, and, as would be expected, the red and yellow pigments

FIG. 7.



Reflection-factors of pigments.

FIG. 8.



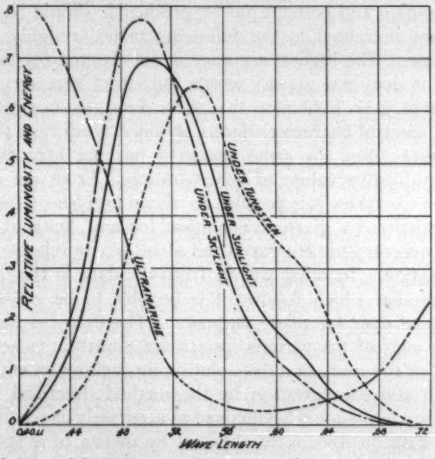
Relative reflection-factors of pigments.

show relatively greater reflection factors for tungsten light than for blue skylight, with the values for sunlight (circles) lying between. It is interesting to note the proximity of the circles to

unity, which represents the relative value of reflection factor in each case for the ideal illuminant having a uniform spectral energy-distribution.

The effect of the illuminant upon the appearance of the color is shown in Fig. 9, using, for example, ultramarine blue, whose spectral energy-distribution is shown. The spectral luminosity-distributions of this pigment for the different illuminants have been computed for equal total amount of reflected light (enclosed areas equal). Thus an idea of the appearance of the color can be formed, or, conversely, the reason for these different appearances under the three illuminants is manifest. Incident-

FIG. 9.



Influence of the illuminant on the appearance of ultramarine pigment.

ally it is seen that this particular pigment is of a purer color under blue skylight than under either of the other illuminants. The wave-length of maximum luminosity is 0.495μ and 0.54μ, respectively, for the skylight and tungsten light. This wave-length of maximum luminosity is not necessarily the dominant hue of the color as analyzed by the eye or by the monochromatic colorimeter, although these are often nearly coincident.

SPECTRAL ANALYSES OF DYE-SOLUTIONS.

The mixture of dyes is governed by the same subtractive principles of color-mixture as the mixture of pigments, although the greater number of dyes and the more exacting or delicate applications of dyes in industries, in the making of accurate filters, etc., make their spectral analyses of perhaps more importance than in the case of pigments. Certainly a knowledge of the spectral characteristics of dyes, as in the case of pigments, makes for an ease and certainty in making and in visualizing mixtures which cannot be enjoyed without such data. It is beyond the scope of this paper to present a complete discussion of the usefulness of spectral analyses of dyes or to present the spectral analyses of all the dyes available; however, a few representative analyses of dyes most common and perhaps most reproducible should be of value. These are presented in the following tables, roughly classified as to color. The highest accuracy is not claimed for these data, because it does not appear worth the effort necessary and because there is no indication that these dyes are, in general, constant in spectral characteristics as obtained from time to time in the market. For the same reason it has not been considered necessary to give values of concentration. From the data presented in the tables it is possible to obtain an idea of the spectral characteristic of a given dye-solution for any depth of the particular concentration employed and also for any relative value of concentration. In other words, from the data in the tables and the discussion which follows it is possible to be guided in the selection of dyes for many purposes. The data for the regions near the ends of the various spectra are uncertain to several per cent. For the study of a dye-solution throughout an entire range of depth and concentration by the method described later the spectral analysis should be obtained as accurately as possible. The present data on dyes were obtained by means of a spectrophotometer, the procedure being such as to eliminate all errors possible with the exception of the uncertainty naturally attending a limited number of observations and that due to ever-present scattered light. In all cases where not indicated otherwise the solvent was distilled water. The dyes were obtained from various well-known commercial sources. Among the solutions will be found a few solutions of metallic salts which are incorporated for their usefulness as filters. All data have been corrected for

surface reflections and for the absorption of the glass cell by the method of substitution.

In Table IV are presented the spectral analyses of a number of dye-solutions commonly classed as red, although many are purple. The sharpness of the absorption or transmission bands is readily visualized from the data, although it is of advantage to plot the data in many cases. There are some excellently sharp bands shown; for example, that of eosine of moderate concentration. In some cases spectral analyses for two concentrations have been presented.

In Table V spectral analyses of a number of yellows are presented. It is noteworthy that there is no known dye which transmits only a narrow region near spectral yellow. The value of sharp absorption bands is seen when a fairly monochromatic filter is desired. For instance, a yellowish-green dye with a sharp cut-off on the long-wave side combined with a greenish-yellow dye with a sharp cut-off on the short-wave side will yield a fairly monochromatic green filter. Some of the dyes fluoresce, which from the point of view of color alone is of considerable interest. Fluorescein and uranine are among the many which fluoresce strikingly. It is interesting to study these by projecting a spectrum upon their upper liquid surface and by viewing the result both from above and from the side. The spectral analyses of potassium bichromate and cobalt chromate are included.

Among the greens in Table VI are a number of dichroics. In fact, a very common characteristic of green dyes is the exhibition of dichromatism. This can readily be ascertained by noting the energy-spectrum or spectral transmission characteristic of one of these dyes. If the transmission factor for red, say 0.7μ, is in any one case greater than that for any wave-length in the other regions of the spectrum (in the green for so-called green dyes), the solution at great depths or concentrations will appear red and therefore will be a dichroic. Naphthol green is an excellent yellowish-green dye. Among the greens presented, malachite, saürgrün, methylengrün, and neptune green exhibit dichromatism.

(To be continued.)

Tinning Cast-Iron. ANON. (*La Chronique Industrielle*, vol. 40, No. 291, p. 12, May 2, 1917.)—For household utensils only pure tin should be employed, and not tin and lead, as the latter forms poisonous salts with the acids of food products. To insure adhesion of the tin, the iron should be treated to remove the carbon, or otherwise it should be polished by mechanical means. To remove the carbon, the iron is coated with a layer of oxide of iron or manganese, or else the iron is enclosed in a box with the oxide and maintained at a high temperature to burn out the carbon. After four to six hours the iron is sufficiently decarbonized to permit the adhesion of the tin.

After this procedure the iron is cleaned with dilute sulphuric acid to which is added a small amount of blue vitriol. The iron is then immersed in molten tin; or, if the interior of a vessel is to be coated, molten tin with a little sal ammoniac is vigorously rubbed over the surface. It is preferable to heat the iron before applying the tin; and this must be done with care, otherwise the surface will be oxidized and impair the adhesion of the tin.

Tendencies of Motor Application. W. L. MERRILL. (*General Electric Review*, vol. xx, No. 6, p. 445, June, 1917.)—The first commercial use of electricity was in the field of lighting, next came railroading, while its use for industrial and power purposes has been a more recent development. Some of the first motor-drive installations made were replacements of steam engines; and in some cases the engine was left intact, so that if trouble developed with the new drive the original method could be resorted to. With the first installations of electric drive there became available a method of more conveniently measuring power than had been possible heretofore. With the old methods of steam drive, the charge was not segregated, the power being so interwoven with the general factory charges that very little was known of the actual cost of power delivered.

The next step in the application of motors was to divide mills or shops into several groups, which might be termed the semi-group drive. This eliminated some of the heavy belting and shafting maintenance; and from a review of conditions at that time it seemed that ultimate economics had been reached. Later, however, tests and data indicated that in a great many industries it was advantageous to still further divide the units of the drive. This consisted in driving with one motor a group of machines that work the same hours on the same product.

In certain classes of machines it has been the practice to employ the individual motor-drive, sometimes belted, sometimes geared, and, again, direct connected. Latterly, motors "built in" as an integral part of the machine drive have shown distinct advantages over the use of a separate standard motor, and the manufacture of many types of machines with self-contained electric drive seems to be rapidly gaining in favor.

PRESENTATION OF THE FRANKLIN MEDAL.
MAY 16, 1917.

At the Stated Meeting of the Committee on Science and the Arts, held March 7, 1917, the following resolutions were adopted:

"*Resolved*, That The Franklin Medal be awarded to Hendrik Antoon Lorentz, President, Royal Academy of Sciences, Amsterdam, Professor of Theoretical and Mathematical Physics in the University of Leiden, in recognition of his researches which have so largely contributed to laying on a new foundation our knowledge of the nature of light and in developing our ideas concerning the ultimate constitution of matter."

"*Resolved*, That The Franklin Medal be awarded to David Watson Taylor, Chief Constructor and Chief of Bureau of Construction and Repair, U. S. Navy, in recognition of his fundamental contributions to the theory of ship resistance and screw propulsion, and of his signal success in the application of correct theory to the practical design of varied types of war vessels in the United States Navy."

CORRESPONDENCE WITH MEDALLISTS.

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

Professor Hendrik Antoon Lorentz, President,
Royal Academy of Sciences,
Amsterdam, Holland.

APRIL 12, 1917.

SIR:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

> "That The Franklin Medal be awarded to Hendrik Antoon Lorentz, President, Royal Academy of Sciences, Amsterdam, Professor of Theoretical and Mathematical Physics in the University of Leiden, in recognition of his researches which have so largely contributed to laying on a new foundation our knowledge of the nature of light and in developing our ideas concerning the ultimate constitution of matter."

The medal and accompanying certificate are being prepared and Chevalier W. L. F. C. van Rappard, your Government's Minister at Washington, has

been requested to come to the Institute on the afternoon of Wednesday, May 16, to receive this medal and certificate, on behalf of his Government, for you.

I am,

Respectfully,

(Signed) R. B. OWENS,
Secretary.

RBO:S

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

MARCH 22, 1917.

Chevalier W. L. F. C. van Rappard,
Envoy Extraordinary and Minister
Plenipotentiary of Her Majesty,
the Queen of the Netherlands.

YOUR EXCELLENCY:

I have the honour to inform you that The Franklin Institute has awarded to Prof. Hendrik Antoon Lorentz, Professor of Mathematical Physics, University of Leiden, Leiden, Holland, The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, have done most to advance a knowledge of physical science or its applications.

The award is minuted as follows:

"That The Franklin Medal be awarded to Hendrik Antoon Lorentz, President, Royal Academy of Sciences, Amsterdam, Professor of Theoretical and Mathematical Physics in the University of Leiden, in recognition of his researches which have so largely contributed to laying on a new foundation our knowledge of the nature of light and in developing our ideas concerning the ultimate constitution of matter."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on Wednesday, May 16, to receive this medal and certificate from our President, on behalf of your Government, for Professor Lorentz.

Two Franklin Medals have been struck this year, one going to Professor Lorentz, and one to Admiral D. W. Taylor, Chief Constructor and Chief of Bureau of Construction and Repair, United States Navy.

You and Admiral Taylor will be asked to be guests of honour at a dinner following the presentation ceremonies, which will probably occur at 4 P.M., but in this connection our President, Dr. Walton Clark, will communicate further with you.

I am

Your Excellency's very humble servant,

(Signed) R. B. OWENS,
Secretary.

RBO:S

WASHINGTON, 23 March, 1917.

KONINKLYK GEZANTSCHAP
DER NEDERLANDEN

No. 1333

MY DEAR MR. SECRETARY:

I am in receipt of your courteous note of the 22nd instant communicating to me the great honor which The Franklin Institute has bestowed upon my countryman, Professor Hendrik Antoon Lorentz, of Leiden, by awarding to him The Franklin Medal for his work in the field of physical science.

I shall consider it, my dear Mr. Secretary, a privilege to receive this medal and certificate on behalf of my Government for Professor Lorentz from the President of the Institute on Wednesday, May 16, in the Institute's Building.

Very sincerely yours,
(Signed) W. L. F. C. v. RAPPARD.

THE SECRETARY OF THE FRANKLIN INSTITUTE,
Philadelphia, Pa.

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

D. W. Taylor, Chief Constructor and
Chief of Bureau of Construction and
Repair, U. S. Navy,
Navy Department,
Washington, D. C.

MARCH 13, 1917.

SIR:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

"That The Franklin Medal be awarded to David Watson Taylor, Chief Constructor and Chief of Bureau of Construction and Repair, U. S. Navy, in recognition of his fundamental contributions to the theory of ship resistance and screw propulsion, and of his signal success in the application of correct theory to the practical design of varied types of war vessels in the United States Navy."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on Wednesday, May 16, to receive this medal and certificate from our President.

I am,
Respectfully,
(Signed) R. B. OWENS,
Secretary.

RBO:S

BUREAU OF CONSTRUCTION AND REPAIR,
NAVY DEPARTMENT
Washington, D. C.

Dr. R. B. Owens,
Secretary, The Franklin Institute,
Philadelphia, Pa.

MARCH 16, 1917.

SIR:

I have the honour to acknowledge the receipt of your communication of March 13, 1917, advising me that The Franklin Institute had made an award to me of The Franklin Medal.

Allow me to express my deep appreciation of the very great honor conferred upon me by the Institute through this award.

It gives me great pleasure to accept the very cordial invitation which you have extended to me, to come to the Institute on Wednesday, May 16, to receive this medal and certificate from your President.

I remain,

Very sincerely yours,
(Signed) D. W. TAYLOR,
Chief Constructor, U. S. N.

PROGRAMME OF MEETING, MAY 16, 1917.

Presentation of The Franklin Medal to His Excellency Chevalier VAN RAPPARD, on behalf of the Royal Netherlands Government, for HENDRIK ANTOON LORENTZ, Ph.D., F.R.S., President, Royal Academy of Sciences, Amsterdam; Professor of Mathematical Physics, University of Leiden.

Presentation of The Franklin Medal to DAVID WATSON TAYLOR, D.Eng., Chief Constructor, Chief of Bureau of Construction and Repair, United States Navy.

Address by Admiral David Watson Taylor, "The Science of Naval Architecture."

PRESENTATION OF THE FRANKLIN MEDAL TO DOCTORS HENDRIK ANTOON LORENTZ AND DAVID WATSON TAYLOR.

In calling the meeting to order the President of the Institute announced that the business of the meeting would be the annual presentation of the Institute's highest award, The Franklin Medal, in recognition of distinguished scientific and technical achievement, and recognized Dr. Harry F. Keller, who made the following statement relative to the work of Doctor Lorentz:

Mr. President: In the choice of the two eminent scientists who, in its opinion, should be recognized this year by the award of The Franklin Medal, the Committee on Science and the Arts

was prompted by a desire to emphasize particularly two of the provisions in the deed of gift of the founder of the medal, Samuel Insull, Esq. They stipulate that this highest award within the gift of the Institute should be bestowed without regard to the nationality of the recipient, and that it should be available for the recognition of highest achievements both in pure science and in its applications. It should be noted, however, that when the committee submitted its report to the Institute the existence of a state of war between our country and the German Empire had not been declared by our Government, and that, in view of this fact, the committee could not have been influenced in its recommendations by any political considerations other than this: that, so long as this country remained neutral, these awards should go only to citizens of countries not actively engaged in the European conflict.

In these circumstances, it is most gratifying to us that the committee's action not only required no revision under the changed conditions, but that, on the contrary, it appears all the more felicitous because of them. For the medallist who represents the purely scientific side of physics is a native and citizen of the same friendly country as the only foreign savant upon whom this distinction has hitherto been conferred; while the other recipient of the medal is a man of pure American stock who has devoted his life to achievements of the first magnitude in connection with the defence of our country and the development of its navy.

The eminent scientists to whom we are about to pay this tribute both achieved their great successes very largely by virtue of their extraordinary command of higher mathematics, and, being myself but a tyro in the science of quantities, it is not without some trepidation, though with a vivid sense of the privilege accorded to me, that I venture upon a brief appreciation of their labors, and that I present to you, Mr. President, the distinguished guests of the Institute who are to accept the medals from your hands.

Under the title "Traité de la Lumière" the celebrated Dutch physicist and astronomer, Christian Huyghens, published in 1690, in the town of Leiden, one of the greatest classics of science, in which he propounded and developed the wave theory of light. For more than a century this hypothesis made little headway

against the corpuscular theory enunciated by Huyghens' great contemporary, Sir Isaac Newton, but at the beginning of the nineteenth century the discoveries of Young and Fresnel paved the way for its general acceptance in a modified and extended form. In our own time, however, this conception that light consists in a wave motion of the ether has again been superseded by another, known as the electro-magnetic theory of light, first proposed by Clerk Maxwell, and our present ideas on the nature of light, and of electricity and radiant heat as well, have been given their present form by the master mind of another great physicist of Holland, whose work also was made known to the world from the town of Leiden.

It is to him that The Franklin Medal for highest achievements in physical science is awarded for this year. Like the lives of other great mathematicians and philosophers, the career of Hendrik Antoon Lorentz has been devoid of picturesque and dramatic incidents; its story is one of single-minded devotion to the advancement of knowledge in the still atmosphere of a small university town. The Who's Whos in Science, while presenting long lists of his achievements and publications, give but a few meagre data concerning his life. From these we gather that he was born July 18, 1853, at Arnheim, the capital of Gelderland, and that he received his university training at Leiden, where he took the degree of Doctor of Philosophy in 1875. After teaching a few years in the public evening school of his native town, he was called to the chair of Mathematical and Theoretical Physics in Leiden University in 1878. At the same time his no less eminent colleague, Prof. H. Kammerlingh Onnes, was elected to the professorship of Experimental Physics, and it is due to these two intellectual giants, working in harmony, and each one supplementing and fructifying the labors of the other, that this university has become one of the world's great centers of physical research. A great number of the noted physicists of this generation have received their training and inspiration from these men, and not a few of the great discoveries and achievements in physical science can be traced to their joint activities.

The investigations of H. A. Lorentz extend over practically all provinces of physical science, but, as has already been indicated, his most important achievements are in the fields of light and electricity, and in the study of the ultimate constitution of

matter. He has published a long series of researches on optic phenomena under the most varied conditions, and it is chiefly to him that we owe the form in which the electro-magnetic theory has gained universal acceptance. His contributions on the structure of the elemental atoms and the nature of electrons rank with those of such investigators as J. J. Thompson and E. Rutherford, and his brilliant and satisfying explanation of the Zeeman effect led to most remarkable discoveries by American astronomers in connection with sun spots, which showed these to be electric cyclones, and thus opened up new fields to solar and stellar research.

His lucid discussion of the positive and negative electrons is still fresh in the memory of those of us who were present at the Franklin Bicentenary, held in this city in 1906, when he came here with his daughter to bring the greetings of the Dutch Academy of Sciences to the American Philosophical Society, and to deliver a course of lectures at Columbia University. Quite a number of books published by Professor Lorentz are recognized as the standard works on the subjects treated. He has been honored by the leading learned societies of the world by being elected an honorary or corresponding member. He is president of the Dutch Academy. In 1902 he was signally honored by the award of the Nobel Prize in Physics.

And now, Mr. President, this venerable Institute of ours delights in joining in this universal tribute to the vast achievements of the majestic intellect of Hendrik Antoon Lorentz. For reasons which require no explanation he cannot be with us to receive The Franklin Medal from your hands, but we are honored by the presence of the distinguished Ambassador of the Royal Netherlands Government who, as we so pleasantly remember, came here two years ago to accept, on behalf of his Government, The Franklin Medal that was then awarded to Professor H. Kammerlingh Onnes, and who will now be pleased to receive from you the medal for Professor Lorentz. I have the honor to present to you His Excellency, Chevalier W. L. F. C. van Rappard, Ambassador of the Royal Netherlands Government.

The President, in presenting The Franklin Medal to Chevalier van Rappard, said:

Your Excellency: For the second time within your term as Ambassador to the United States the work of a Netherlands

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scientist has commended itself to The Franklin Institute as worthy of the highest honor in the gift of the Institute. Therefore, for the second time, it is my pleasure and my honor to entrust to you The Franklin Medal for transmission, through the State Department of your gracious Queen, to one of her subjects, the medallist in this instance being Professor Hendrik Antoon Lorentz, President of the Royal Academy of Sciences of Amsterdam.

In accepting the medal for Doctor Lorentz, Chevalier van Rappard said:

Mr. President, Members of The Franklin Institute of the State of Pennsylvania, Ladies and Gentlemen: For the second time the great honor has been conferred upon me to accept, in the name of my Government, The Franklin Medal on behalf of one of my most distinguished countrymen. This fills me with joy and pride. It is most gratifying to me, as the representative of the Netherlands, to see in this new appreciation of the science and of the talents of a Hollander that it is not absolutely necessary to be a great power to produce to the world great men; that also a country, hardly the size of the state of Maryland, is able to prove by such men as Professor Lorentz and Professor Onnes that she deserves a prominent place among the nations of the earth, and that Holland has not been inferior to the larger nations in ideals and in her contributions to human progress and to civilization.

Though Napoleon called Holland a mere deposit of German mud vomited by the Rhine, and though Andrew Marvell, long before him, spoke of it as the offscouring of the British sand, adding that the people fished the land to shore, and though many others have waxed facetious over Holland's oddity, one poet characterizing the Netherlands as a land "Where people do not live, but go aboard," yet those who have studied her history concede that she has played as great a part in human affairs as countries to whom Nature was more kind. Her chief advantages were her disadvantages, for these made possible the survival of only the fittest.

This year you again honored a descendant of those old Hollanders, and by that selection you again showed to the scientific world that in science and learning my dear, small country holds its own, and that still now the Netherlands belong to the

most inventive of all the nations of Europe as they were in the past, when they were inventive under the spur of necessity.

With your permission I deem it fitting to mention here a few of the Hollanders' many inventions. In the Netherlands originated the sawmill, the windmill, wood-engraving, oil painting, the printing of letters from wooden blocks, which preceded the movable type of the Germans; the thimble, spectacles, window glass, the use of the greenhouse in horticulture, the iron plow, counterpoint in music, the telescope and the microscope, upon the use of which all modern science is based; the mariner's compass, and the thermometer.

It was Christian Huyghens who, besides originating the theory of the vibration of light, was the first to apply the micrometer to the telescope; less known, but not less important, is the work of Stevinus, who, in 1586, by his book on "The Principles of Equilibrium," founded the Science of Statics, who introduced decimal fractions, and who predicted the world's adoption of decimal coinage, weights, and measures.

It is particularly gratifying to me that Professor Lorentz, upon whom you bestowed this year the greatest distinction you dispose of, belongs also to the University of Leiden. You all know how the University of Leiden originated: Preferring learning to "perpetual immunity" from taxes, the citizens founded and fostered what is perhaps the greatest of all modern universities, for no other institution has produced so many great men. On the roster of its professors and students are hundreds of lasting renown, among others: Scaliger, Vossius, Heinsius, Christian Huyghens, the great Grotius, Hooft, Rembrandt the painter, Lipsius, the philologist and historian; Boerhaave, the great physician; Drusus, the Orientalist; Gomarus and Arminius, the theologians, and hundreds of others.

In Leiden, too, were printed the Elzevirs and all books that could not get a hearing elsewhere. And it is an index to the education of the people and to the status of the country to learn that fifteen editions of the Old Testament and twenty-four of the New had been printed and published at Leiden before the first Bible was printed in England.

I hope you won't take it amiss nor consider me conceited because I have drawn for a moment your attention upon our oldest University and upon my brave little country. You have

brought that upon yourselves by again, in the person of Professor Lorentz, as you did a few years ago in the person of Professor Onnes, distinguishing a countryman of mine and giving again a testimonial of the highest value to a modest worker of the Low Countries, who gives himself entirely to the science, and who surely will see in the great distinction offered to him by your institution not only a great reward for what he has done till now, but also a great encouragement to continue his successful work.

In the name of the Government of Her Majesty, my gracious Queen, I declare to accept, with the expression of Professor Lorentz's and of Holland's most sincere thanks, on behalf of my countryman, Professor Lorentz, of the University of Leiden, The Franklin Medal, and I express the hope that this renewed proof of esteem given by your great new country will lead to an (if possible) still closer bond with the small old country at the other side of the ocean.

In introducing Doctor Taylor, Doctor Keller said:

Mr. President: While this Institute derives very great satisfaction from its ability to fittingly recognize the lifework of a scientist like Professor Lorentz, it is no less gratifying to our membership to witness the presentation of The Franklin Medal to a compatriot who has to his credit so many achievements of the highest order in the application of physical science to our welfare and national defence. The career of this medallist must be a source of intense pride and an inspiration to every American; for his achievements are such as to place him in the foremost rank of naval engineers of any country and of any time.

He was born March 4, 1864, in Louisa County, Virginia, as a lineal descendant of distinguished soldiers and statesmen of the Revolutionary period. His early education and preparation for college he acquired by home instruction and study, entering the Randolph-Macon College in Virginia as a mere boy of thirteen. On completing the four-year course in this institution in 1884, he won an appointment as cadet engineer in the Naval Academy at Annapolis, attaining second place among 130 competitors from the country-at-large. He graduated in 1885 at the head of his class, and with the highest percentage of marks for the entire course ever attained by any graduate of the academy before or since that date. In the fall of the same year he was ordered

to London to enter a three-year post-graduate course in naval architecture at the Royal Naval College at Greenwich. At the end of the first year he had made such a high record in scholarship that the Secretary of the Navy appointed him an assistant constructor with the rank of junior lieutenant, and upon the completion of the entire course he established a record for percentage of marks which has never been equalled by any graduate of the college, either before or since that time.

His career of constructive work he began as a member of the Corps of Naval Constructors of our Navy, in which position he greatly distinguished himself by solving a number of important problems in connection with the resistance and power of ships. The results of this work are recorded in numerous papers which he presented before the leading engineering societies of the world, and in two comprehensive treatises. The gold medal of the British Institute of Naval Architects was awarded to him for a paper entitled "On Ship-shaped Stream Forms," while another paper, under the title "The Theoretical and Practical Methods of Balancing Marine Engines," won for its author the first prize in a competition of the American Society of Naval Architects and Marine Engineers. His books on the "Resistance of Ships and Screw Propulsion" and on "The Speed and Power of Ships" have come to be universally recognized as the standard works upon these subjects.

But his most important contributions to the scientific side of naval architecture are based upon the work he conducted at the United States Experimental Model Basin, which he designed and constructed at Washington, D. C., in 1897, and of which he had charge until 1914. During this period of his life a surprisingly wide range of subjects engaged his attention, and many instances might be cited in illustration of his resourcefulness in formulating and experimentally attacking problems in subjects of which very little was known before. A case in point is his brilliant experimental researches on "The Interaction Due to Suction between Passing Vessels," a subject on which there was little or no reliable information, save a few observations on cases of damage to ships by unexplained collisions. By his brilliantly conceived and successfully conducted experiments he placed the subject on a scientific basis, and this work aroused such a widespread interest that, at the time of the trial in England of the

celebrated case arising from the collision between the White Star liner *Olympic* with the British cruiser *Hawk*, he was invited, both by the British Government and the owners of the *Olympic*, to appear as an expert witness.

During the years he had charge of the Model Basin he by no means confined his attention to the theoretical aspects of naval architecture, but he was also the principal adviser to the Chief Constructor of the Navy on all matters pertaining to the design of every vessel of importance on the navy list. It was in this capacity that he conceived what is now known as the "American" or "centre-line" arrangement of gun turrets on the "Dreadnought" or "big-gun" type battleships built for the American navy, and which has since been adopted by every great Naval Power.

In December, 1914, he was appointed, by the President, Chief Constructor of the United States Navy, with the rank of Rear Admiral, and Chief of the Bureau of Construction and Repair. In this capacity he has been responsible for the design and building of the huge naval program provided for during the last two years.

The sparing intervals of leisure in his busy life he loves to spend on his country place in Virginia, where he successfully applies scientific principles to farming on a large scale.

Mr. President, at this time when our country's safety and success in the great war depend so largely upon a powerful and efficient navy I deem it a special honor and privilege to present to you as Franklin Medallist a man who has played a foremost part in its development, and who is conceded to be the greatest living naval architect and naval constructor, Admiral David Watson Taylor.

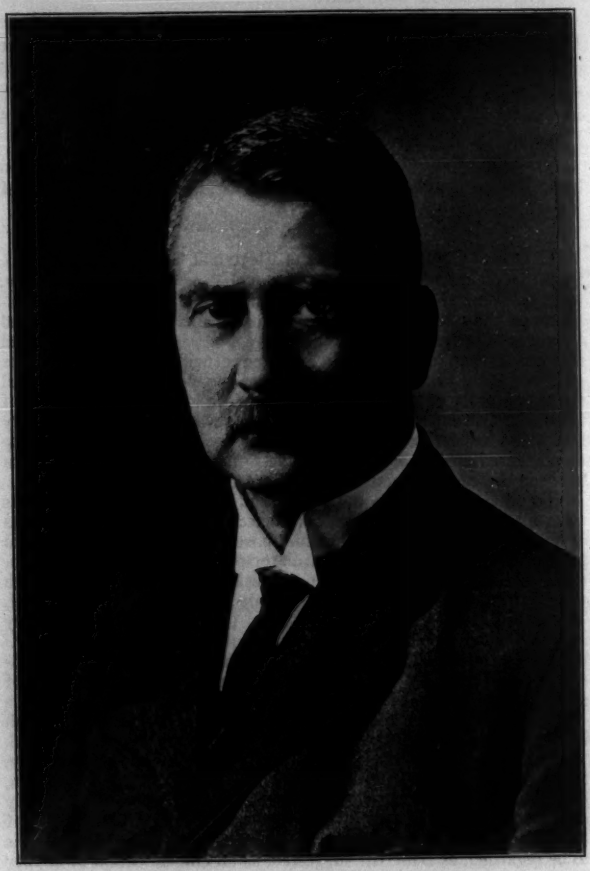
Before presenting the medal to Admiral Taylor, the President read the following message from the Honorable Josephus Daniels, Secretary of the Navy:

WESTERN UNION TELEGRAM

Dr. R. B. Owens,

Secretary, The Franklin Institute, Philadelphia, Pa.

I regret that official duties deny me the pleasure of being present today when The Franklin Institute awards The Franklin Medal to Admiral Taylor. No distinction has been awarded by any institution to a man who deserved it more. Admiral Taylor is not only an honor to the Navy, but has added lustre to American accomplishment in a field calling for the highest ability. JOSEPHUS DANIELS.



DAVID WATSON TAYLOR

The President then said:

Admiral Taylor: I have the honor, in the name of The Franklin Institute, upon the recommendation of its Committee on Science and the Arts, and in recognition of your distinguished services to humanity, and particularly to your nation, rendered in the field of science, to present you The Franklin Medal and Diploma, the highest honor in the gift of the Institute.

After expressing his appreciation of the honor conferred upon him, Doctor Taylor read a paper entitled: "The Science of Naval Architecture" (see page 1).

Chemical Composition Versus Electrical Conductivity. C. G. FINK. (*General Electric Review,* vol. xx, No. 5, 363, May, 1917.)—Some years ago the author carried out a number of experiments on the electro-thermic production of ultramarine. Powdered mixtures of sodium sulphide, china clay, and carbon were interposed between carbon electrodes in a closed crucible furnace. It was observed at the time that in order to keep the electrical resistance and the temperature of the charge low enough to avoid decomposition of the ultramarine as soon as it was formed it was necessary to use very finely divided carbon, such as lampblack. With charges made up of powdered coke it was not possible to pass an appreciable current between the carbon electrodes up to potentials of 250 volts.

To obtain values of a more quantitative nature, a series of tests were made. Two substances were selected, the physical properties of one as divergent as possible from those of the other: a black metal powder, tungsten, and a white insulator powder, thoria. The advantages are that both tungsten and thoria will withstand very high temperatures and can therefore be made practically moisture-proof. The results showed, in general, that the electrical conductivity of a substance is primarily dependent upon the shape and the distribution of the fundamental grains or particles composing the substance, and, secondly, upon the presence or absence of thin films of secondary material enveloping these ultimate grains. On the basis of these conclusions we can account for the comparatively high conductivity of gels that contain but a trace of conducting material. We can also account for the marked difference in resistance of, say, two samples of commercial copper of identical chemical composition, depending upon whether the impurity, such as sulphur, is uniformly dissolved in the metal or whether it forms a film ("cement") of copper sulphide around pure granules of copper. The latter case is to be regarded, as Bancroft suggested, as an emulsification of copper in copper sulphide. The high resistance of these surface films composed of, say, sulphide or oxide or arsenide accounts for the high resistivity values of copper containing but a trace of one or more of these impurities.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE CALCULATION OF THE CONSTANTS OF PLANCK'S RADIATION EQUATION; AN EXTENSION OF THE THEORY OF LEAST SQUARES.[1]

By Harry M. Roeser.

[ABSTRACT.]

THE problem of computing from experimental data the constants, c_1 and c_2, of Planck's radiation equation for the distribution of energy in the spectrum of a black body is attacked by the method of least squares. The data were furnished by Dr. W. W. Coblentz and had been used to determine the constant c_2 by another method (*Bulletin Bureau of Standards*, 13, 1916, p. 474).

The observation equations were reduced by taking logarithms of both sides and assigning proper weights to the equations so transformed. The method of assigning weights is given in a general form that can be adapted to any scheme of transformation.

It is shown that the "two point" method (*Bulletin Bureau of Standards*, 13, 1916, p. 535) of determining c_2 may be made identical with the least square solution if all possible pairs of points are combined and a proper system of weights is applied to the separately computed values before taking the mean. This is suggested in T. W. Wright, "Adjustment of Observations," 1884, page 141. A short numerical example is given to show that by this system of weights being applied to an arbitrarily selected number of computed values the weighted mean approximates the least square value better than the simple mean.

THE LUMINOUS RADIATION FROM A BLACK BODY AND THE MECHANICAL EQUIVALENT OF LIGHT.[2]

By W. W. Coblentz and W. B. Emerson.

[ABSTRACT.]

THIS paper gives applications of the visibility of radiation of the average eye to radiation problems, including the luminous energy emitted by a black body at various temperatures, the

* Communicated by the Director.

[1] Scientific Paper No. 204.

[2] Scientific Paper No. 305.

luminous efficiency, the Crova wave-length, and the mechanical equivalent of light.

The visibility curve of the average eye (125 observers) gives a mechanical equivalent of 1 lumen = 0.00161 watt of radiant energy of maximum visibility. Various other determinations give values varying from 0.00157 to 0.00160 watt.

The most reliable data now available indicate a value of 1 lumen = 0.0016 watt of radiant energy of maximum visibility; or 1 watt = 625 lumens = 49.8 candles of radiant energy of maximum luminous efficiency.

AN EXPERIMENTAL STUDY OF THE FAHY PERMEAMETER.[1]

By Charles W. Burrows and Raymond L. Sanford.

[ABSTRACT.]

THIS permeameter was developed during the course of an investigation at the Bureau of Standards on the magnetic-mechanical properties of steel. In order to ascertain the degree of accuracy attained, as well as its fitness for general laboratory use, a critical experimental study of the instrument in its present form has been made.

The instrument represents a distinct advance in the measurement of the magnetic characteristics of steel and other magnetic materials. In accuracy it far excels the direct-reading permeameters which have been rather commonly used both in this country and abroad. Normal induction measurements of solid bars show errors no greater than five per cent. of the magnetizing force required for a given induction. The consistency of its readings taken at different times on the same specimen is so close that comparative results on similar materials can be obtained to a much higher degree of precision. Commercial materials, however, are seldom uniform enough to warrant better precision than five per cent. Hysteresis measurements are accurate within the limits of commercial requirements and the uniformity of commercial materials.

[1] Scientific Paper No. 206.

NOTE ON ELECTRICAL CONDUCTION IN METALS AT LOW TEMPERATURES.[1]

By Francis B. Silsbee.

[ABSTRACT.]

THE experiments at the University of Leiden at extremely low temperatures have shown that certain metals show an abnormally great electrical conductivity. It has also been discovered that if either the magnitude of the current flowing in the specimen, or the magnetic field in which the specimen may be placed, is increased above a certain critical value, then this abnormal conductivity disappears. In this paper it is pointed out that these two experimental facts are not independent, but that the phenomenon of critical current is a necessary consequence of the existence of a critical value of magnetic field. The relation between the two is that the critical value of the current is that at which the magnetic field due to the current itself is equal to the critical magnetic field. On account of the great experimental difficulties connected with work in this range of temperature, the quantitative data available for testing this relation are rather scanty as yet, but the data which are available are in satisfactory agreement with the theory.

GAS CALORIMETER TABLES.[2]

[ABSTRACT.]

THE numerous requests for a brief and concise set of operating directions for a gas calorimeter, and for a convenient set of correction tables, has resulted in the publication by the Bureau of Standards of Circular No. 65, "Gas Calorimeter Tables." This may be regarded as a supplement to Bureau Circular No. 48, "Standard Methods of Gas Testing." The correction tables are arranged in a sequence most convenient for use in connection with the proposed record sheet.

The record forms for calorimeter tests which are shown in the circular have been used for some time and found to be complete and convenient. It is hoped that these forms will be adopted wherever possible, so that there will be greater uniformity in operating methods and the records used. The Bureau is willing to loan the original plates for preparation of electrotypes for these blanks to any one desiring to print them.

[1] Scientific Paper No. 207.

[2] Circular No. 65.

COMPARATIVE TESTS OF STITCHES AND SEAMS.[1]

By Walter S. Lewis.

[ABSTRACT.]

THIS work was undertaken with a view of determining the essential differences between seams produced by two methods of stitching by the sewing machines most extensively employed. Seams of the double-locked stitch and the shuttle stitch, sometimes called lock stitch, were tested to show their relative strength and other characteristics.

DOUBLE-LOCKED STITCH.

The double-locked stitch is produced without the use of a shuttle, and in the formation of a seam all threads are fed directly from original spools or bobbins without any rewinding. The under thread is called the looper thread and is guided into place by a small metal arm, containing an eye through which the thread passes. This arm works back and forth, forming one part of the stitch as the needle or upper thread works up and down through the fabric. Inasmuch as no shuttle is employed, there is no time lost in rewinding a bobbin or refilling a shuttle, which is necessary with the sewing machine commonly used in the household.

SHUTTLE STITCH.

The shuttle stitch is produced by the use of a shuttle which supplies the under thread while the upper thread passes through the needle. With this method of stitching the shuttle must be removed from the machine, from time to time, to refill the bobbin.

STRENGTH OF SEAMS.

Several kinds of fabric were stitched by each method and by using various combinations of thread sizes. The seams thus produced were tested to determine which method of stitching produces the stronger seam, greater stretch, etc. Various types of tensile strength test specimens were used, and it is believed that these gave a fair comparison of the strength of the two types of seams tested.

[1] Technologic Paper No. 96.

EFFECT OF A BROKEN STITCHING THREAD.

Comparative tests were made with specimens in which the stitching thread was broken. It was found that the shuttle-stitch seam was weakened much more than the double-locked stitch, and the pulling out of the threads in the former stitch caused the seam to give way before the fabric was torn. This is objectionable, because the hole thus produced must be sewed up to prevent it becoming larger. With the double-locked stitched seam, however, a broken stitch does not produce a hole, as each loose end becomes securely locked and the seam remains as strong as it was originally.

Other tests were made to show the stretching qualities of the two kinds of stitching. The results of these tests show that the double-locked stitch is more elastic, stronger, and less likely to be injured by tension along the seam than the shuttle method of stitching.

The results of this investigation show that seams produced by the double-locked stitch are superior to the shuttle stitch. No attempt was made to compare the two types of stitching in other respects, such as production capacity of the two types of machines; cost of production, with special reference to consumption of time, thread, and fabric; deterioration due to wear, etc.

Acid-resisting Properties of Some Iron-silicon Alloys. O. L. KOWALKE. (*Proceedings of the American Electrochemical Society*, May 2–5, 1917.)—Various acid-resisting alloys of commercial importance have been produced within recent years, and among these the iron-silicon alloys seem to give satisfactory service in many operations. Little information, however, seems to have been published on the acid-resisting properties of the iron-silicon alloys, and an investigation was undertaken to determine their resistance to several common acids.

Eighteen low-carbon iron-silicon alloys, containing 1.2 to 19.8 per cent. of silicon, were immersed from periods of 51 hours to 29 days in 10 per cent. solutions of sulphuric, hydrochloric, nitric, acetic, and citric acids, and the losses determined. With a few irregularities the resistance to acid attack was a minimum at 1.2 to 3.3 per cent. silicon, and a maximum at 16 to 18 per cent. The latter alloys are very hard and brittle. Attempts are being made to find an addition element which will decrease these undesirable qualities without impairing the resistance to acids.

Automobile Headlighting. S. C. ROGERS. (*Transactions of the Illuminating Engineering Society*, vol. xii, No. 3, p. 158, April 30, 1917.)—Judging by the generally unsatisfactory results which have been obtained up to the present time in endeavoring to secure adequate road lighting without presenting intolerable glare to persons facing the headlamp, the practical problem presented by the regulation of the use of high-power headlamps is apparently an extremely difficult one. Only by the close application of a thorough knowledge of the processes of vision and the requirements of headlighting may a satisfactory compromise be effected.

If it were possible to secure a point light source, a true paraboloid would project a cylindrical beam of the same diameter as the reflector and consisting of wholly parallel rays, provided that the light source were at the focus. If this point light source were placed behind the focus, a conical beam consisting of entirely divergent rays would result. If this point light source were moved in front of the focus, an "hour glass" beam consisting of converging rays would result. Likewise, if the light source were moved in a vertical plane perpendicular to the axis of the paraboloid at its focus, the beam would be lowered or raised, depending upon whether the light source were raised or lowered. Light sources have physical dimensions, however, and the spread of the beam will depend upon the size and shape of light source used and also upon the location of the latter with respect to the focus of the paraboloid.

Ability to detect persons, objects, etc., at a considerable distance in front of the car depends upon various factors. The high candlepowers used are sufficient, but the characteristics of road surfaces and the adaptability to darkness of the eye must be considered. It has been commonly asserted by many that a beam of yellow light will penetrate fog or dust better and will produce less glare than the same intensity beam of white light. It should be borne in mind that yellow light for headlamp work is not the same yellow light for general illumination. As a result of many headlamp tests, no reduction in glare has been found, except that directly traceable to the lesser intensity of the headlamp due to the absorption of the glass, nor any better penetration of fog, dust, or smoke. The only advantage that could be found was a reduction of the diffractive halation or back glare when driving through a rainstorm or heavy fog. On the other hand, halation around an opposing headlamp usually results in reducing the contrast glare. Over two thousand methods have been developed for overcoming the dazzling rays or glare. Among these commonly seen at present are: parabolic reflectors with devices placed in the path of the reflected light, parabolic reflectors with devices placed between light source and reflector, special light sources, and reflectors of special designs and shapes.

NOTES FROM RESEARCH DIVISION, ELECTRICAL ENGINEERING DEPARTMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY.*

CONVECTION OF HEAT FROM SMALL WIRES IN WATER.

THE laws of the forced convection of heat from small wires carrying a steady electric current and moving transversely through air have been studied at some length.[1] A research into the case of small wires moving transversely in water was carried out by Messrs. Harold Worthington and C. B. Malone, Jr., as a thesis towards the S.B. degree, at the Massachusetts Institute of Technology, in 1915, under the direction of the Electrical Engineering Research Division. The results obtained are here briefly summarized.

The test wire was of platinum, No. 30 A. W. G. (0.256 mm. diameter), supported in a vertical frame holder. The latter was carried on the end of a motor-driven rotating arm in such a manner that the test wire was dragged through the water of a large tank, in a direction transverse to its length, at an adjustable velocity, and at a constant depth of immersion. The vertical frame was of steel, 41 cm. high, and designed so as to grip the test wire tightly, and to keep the latter vertically stretched, while stirring up the water as little as possible in the path of the wire's motion. The test wire was about 20 cm. long, and was connected by the grips of the holder to a storage battery through a controlling resistance and ammeter. In this way the current I, through the test wire, could be carried up to 17 ampères, under adjustable control. Pressure wires, fastened to the test wire, and 12.8 cm. apart, were led to a voltmeter, so as to show the drop of potential V in this working portion of the test wire. The product VI of the observed voltage and current gave the power dissipated by the wire, in watts, and this, divided by 12.8, gave the linear power dissipation in watts per linear centimetre of the test wire. The ratio V/I also indicated the working resistance of the 12.8 cm. of wire, and from this the mean temperature of the test wire became known.

* Communicated by the Director.

[1] JOURNAL OF THE FRANKLIN INSTITUTE, June, 1917, p. 783.

It was found that the linear power P, dissipated from the test wire convectively, as the wire was hauled around in the water tank, was proportional to the temperature difference θ between the wire and the mass of the water, *i.e.*, to the temperature elevation of the wire, for velocities above 6 cm. per second. At velocities lower than this, the proportionality appeared to fail, perhaps because of irregular convection in the water due to liquid eddies.

The forced convection, for a given temperature elevation $\theta°$ C. of the wire, varied exponentially with the velocity V of the wire's transverse motion. At temperature elevations not exceeding 23° C., the linear dissipation P varied as the square root of the velocity, or as $V^{1/2}$. At higher temperature elevations, the exponent appeared to fall off, according to an empirical relation: exponent $= 0.55 - 0.003\theta$. The reason for this falling off in the exponent at higher values of θ is not known. It will be noted, however, that the activity in watts per square centimetre of wire surface becomes surprisingly large as θ is increased.

Within the limitations above indicated, the linear dissipation was found to follow the relation

$$P = 0.031\,\theta\,\sqrt{V} \text{ watts per linear centimetre} \quad (1)$$

where θ is the temperature elevation and V is the velocity of the wire's motion in centimetres per second, taking into account a certain experimental virtual velocity $v_0 = 1.15$ when the wire is at rest, and explainable as a velocity of free convection; that is,

$$V = v + 1.15 \text{ centimetres per second} \quad (2),$$

v being the true velocity of the wire through the water.

The total range of velocities v experimented with was from 0 to 16 cm. per second. It was not convenient to carry the velocity to higher values than 16 cm. per second, because of the stresses brought on the test wire and of the disturbances set up in the liquid. The dissipation for $\theta = 30°$ C., and $v = 14.85$, or $V = 16$ cm. per second, would be, by (1), 3.7 watts per linear centimetre. This corresponds to 46 watts per square centimetre of test-wire surface.

In all of the later tests filtered tap-water from the Boston City mains was used. It was found that the surface coefficient

0.031, in (1), could not be depended upon to keep constant for more than a few minutes at a time unless the wire's surface was cleansed by wiping it. A transparent superficial layer of dirt seems to form rapidly on the heated wire, and this causes the linear dissipation to diminish. Consequently any attempt to use the device for measuring the velocity of such water, passing the wire, would seem to call for some means of cleansing the wire at short, regular intervals.

It is interesting to note that the linear dissipation from a thin platinum wire in water, as above described, is more than one hundred times greater than that from a thin copper wire of the same diameter moving in air, at the same velocity and temperature elevation.

The Vosmaer Phenomenon. W. C. MOORE. (*Proceedings of the American Electrochemical Society*, May 2–5, 1917.)—A number of years ago a patent was issued to A. Vosmaer, of Haarlem, Holland (English patent, No. 21,887, 1899), for the production of light by means of a discharge between nickel wires serving as the secondary terminals of an induction coil. The phenomena involved were described by Vosmaer in *Metallurgical and Chemical Engineering* for June, 1914. In brief, when the wires used are of the correct size for the induction coil to which they are connected, and the distance between the ends of the wires is properly adjusted, the cathode wire fuses at the end, forming a small globule which glows with high intrinsic brilliancy.

Experiments made in the Research Laboratory of the National Carbon Company, Cleveland, Ohio, using a coil giving a normal spark of three inches, showed that (1) on turning on the current the cathode becomes intensely hot at its extreme end, and soon melts; (2) that the surface tension of the molten nickel is sufficiently great to draw the molten material up into a ball; (3) that while (1) and (2) are taking place, the outer portion of the fused mass becomes oxidized. This oxide adheres very firmly to the nickel, as it apparently has a higher melting-point than nickel, the nickel is protected from further attack and so is not consumed, and an equilibrium temperature is therefore soon reached. The fact that the ball, when the energy is liberated, is much larger than the wire, and the heat of conductivity decreases very rapidly with the temperature, causes this equilibrium temperature to attain a high value. The high emissivity of the nickel-oxide layer explains the high intrinsic brilliancy of the little ball.

New Alloys to Replace Platinum. F. A. FAHRENWALD. (*The Journal of Industrial and Engineering Chemistry*, vol. 9, No. 6, p. 590, June, 1917.)—The present phenomenal activities in chemical research and manufacturing enterprises have resulted in a continually increasing consumption of platinum, while statistics show that the world's production has been on the decline. At the present time an actual scarcity of the metal is of greater importance than its consequent high cost. The development of materials to take the place of platinum in many of its applications has consequently become not so much a matter of economic desire as one of actual necessity.

At the present time, when molecules, atoms, and electrons are a matter of fruitful study, the production of alloys of special properties is no longer the result of discovery, as in the days of the alchemist, and advances are now made by a study of the relation of the general properties of an alloy to the nature of its constituents. The relationship of the elements, best revealed by some form of the periodic table, showed that the general properties of platinum were possessed by no other metals except those adjacent to it in the table. The surrounding elements are iridium, rhodinium, palladium, silver, and gold. All metals outside of this region are affected by common reagents and gases, and without exception are not stable at elevated temperatures in normal atmospheres. Considering each of these in turn, it was found that not one is suited as a general substitute for platinum. The possibilities being limited to the small group indicated, it was necessary to combine these included metals in such a manner as to eliminate or neutralize undesirable features, and to develop those which were necessary. Among these, only gold and palladium were found available as the permissible *chief* components of an alloy having nearly the general properties of platinum.

A detailed investigation of alloys of these metals has resulted in materials which for many practical purposes cannot be distinguished from platinum. The name "rhotanium" has been applied to this series of alloys. Exhaustive tests have shown that most of the uses for which platinum has heretofore been considered indispensable can be filled by one of these gold-palladium alloys, thus freeing platinum for those remaining applications where no other material can be employed. The extent to which platinum may be replaced in this manner is limited by the amount of palladium available, and when it is considered that these alloys contain from 90 to 60 per cent. of gold it is evident that the effective supply of platinum may thus be increased by many thousand ounces.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE VOLATILE REDUCING SUBSTANCE IN CIDER VINEGAR.[1]

By R. W. Balcom.

[ABSTRACT.]

A HISTORICAL discussion is followed by experimental results which include details of the preparation and purification of the phenylosazone obtained from the distillate from cider vinegar. Such distillates contain a reducing substance which reduces Fehling's solution at room temperature. The melting-point of the phenylosazone and the amount of nitrogen it contained indicated that it was diacetyl phenylosazone. Diacetyl (CH_3–CO–CO–CH_3) and acetylmethylcarbinol (CH_3–CHOH–CO–CH_3), the two substances from which this osazone might be formed, were prepared and the behavior of dilute solutions of these two substances was compared with that of the cider vinegar distillate. It is shown that the reducing substance in the cider vinegar distillate is largely, if not wholly, acetylmethylcarbinol. This substance is not formed during the distillation of the vinegar. It is present as such in the vinegar and appears to be a normal constituent of cider vinegar.

SOME PROTEINS FROM THE JACK BEAN (CANAVALIA ENSIFORMIS).*

By D. Breese Jones and Carl O. Johns.

From the Protein Investigation Laboratory, Bureau of Chemistry, Department of Agriculture, Washington, D. C.

[ABSTRACT.]

Two globulins, *canavalin* and *concanavalin*, and an albumin have been isolated from the jack bean. The air-dried jack bean meal contained 23 per cent. of protein, 15 per cent. of which is extracted from the meal by distilled water. A two per cent. sodium chloride solution extracted 18.5 per cent., and a 0.2 per cent. potassium hydroxide solution extracted nearly all of the

* Communicated by the Chief of the Bureau.

[1] *J. Am. Chem. Soc.*, 39, 309–315 (February, 1917).

protein, or 22.3 per cent. By mixing the meal with three times its weight of 10 per cent. sodium chloride solution, and this mixture ground in a mill to break up the cells, 20.5 per cent. of protein was extracted ($N \times 6.25$). Dialysis of salt extracts of the jack bean against distilled water yielded about 10 per cent. of pure, dry globulin, based on the weight of the meal used. The globulin was so soluble in salt solutions that it could not be precipitated by diluting these solutions with water. After the globulins had been removed, about 1.5 per cent. of an albumin was isolated as a flocculent coagulum from the dialysate by heating the latter to 75 to 80°. The globulin of the jack bean is not identical with phaseolin, isolated by Osborne from the kidney bean (*Phaseolus vulgaris*). Concanavalin, the globulin present in the jack bean in the smaller amount, and which is the less soluble, was precipitated from a one per cent. salt extract of the meal by adding ammonium sulphate to 0.6 of saturation. The precipitate was filtered off, redissolved in water, and dialyzed until free from sulphates. Canavalin was obtained by making the filtrate from the concanavalin completely saturated with ammonium sulphate. The chief difference between canavalin and concanavalin lies in their sulphur content; namely, 0.48 and 1.10 per cent. respectively. It is evident, from the analyses of these two globulins, that only a small amount of concanavalin can be present in the mixture of globulins obtained by dialysis, since the sulphur content of canavalin and the mixture of globulins are practically the same. Canavalin contains 3.17 per cent. of basic nitrogen. The albumin, which contains 3.73 per cent. of basic nitrogen, resembles the legumelins which have been described by Osborne and his co-workers.

THE PROTEINS OF THE PEANUT (ARACHIS HYPOGÆA).[1]

By Carl O. Johns and D. Breese Jones.

From the Protein Investigation Laboratory, Bureau of Chemistry, Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THE recent increase in the production of peanuts in the United States has stimulated a special interest in the peanut from an economic standpoint. The proteins of the peanut have received but little attention. The only published experiments seem to be

[1] *The Journal of Biological Chemistry*, vol. 28, 77 (1916)

those described by Ritthausen in a paper which appeared in 1880. The present investigation has shown that the proteins of the peanut consist chiefly of two globulins, *arachin and conarachin*. A small amount of albumin has also been isolated. The investigations were carried out on oil-free peanut meal obtained by pressing out most of the oil from raw Virginia peanuts by means of an Anderson expeller. The resulting press cake was then ground to a fine meal and the residual oil removed by extraction with petroleum ether. This meal contained 18 per cent. of nitrogen, equivalent to 45 per cent. of protein ($N \times 5.5$). By extracting the meal with 10 per cent. sodium chloride solution, 32 per cent. protein, based on the weight of meal used, is dissolved at room temperature, 78 per cent. of which was actually isolated in pure form by diluting the salt extract with five to six volumes of distilled water, or by saturating with carbon dioxide. The same globulins were also obtained by dialysis of the salt solution. Arachin and conarachin were isolated by means of fractional precipitation of the protein extracted by salt solution.

Arachin, which represents the greater part of the total globulins, is the less soluble of the two, and is precipitated when in 10 per cent. salt solution by adding ammonium sulphate to 0.2 of saturation. After filtering off the arachin, conarachin can be obtained by dialysis, or by saturating the filtrate with ammonium sulphate. The greatest difference between these two globulins is in percentage of sulphur; namely, 0.40 and 1.09 per cent. respectively. Another striking difference is shown by the figures representing the distribution of nitrogen, particularly in the percentage of basic nitrogen, being 4.96 and 6.55 per cent. respectively. The percentage of basic nitrogen in the mixture of these globulins is also high, being 5.23 per cent. So far as known, conarachin contains more basic nitrogen than any other seed globulin yet examined. From the results obtained it seems probable that peanut press cake will prove to be highly effective in supplementing food products made from cereals and other seeds whose proteins are deficient in the basic amino-acids.

KAFIRIN, AN ALCOHOL-SOLUBLE PROTEIN FROM KAFIR (ANDROPOGON SORGHUM).[1]

By Carl O. Johns and J. F. Brewster.

From the Protein Investigation Laboratory, Bureau of Chemistry
Department of Agriculture, Washington, D. C.

[ABSTRACT.]

HITHERTO no study has been reported on the proteins of kafir. The seeds used in this investigation were grown in Kansas, and were of the variety known as dwarf kafir. The ground seeds contained 11.7 per cent. of protein (N × 6.25), 7.9 per cent. of which was extracted from the meal by boiling 60 per cent. alcohol. There was isolated, by the use of alcohol ranging from 60 to 70 per cent., 5.2 per cent. of the pure protein, *kafirin*. In its ultimate composition kafirin closely resembles zein from maize. While zein is very soluble in 70 per cent. alcohol at all temperatures, kafirin requires a large quantity of the same strength of alcohol to effect solution. Kafirin is much more soluble in hot than in cold alcohol, and even rather dilute solutions will give a jelly on cooling. On this account it was necessary to use large volumes of alcohol, and to filter the extracts while hot. Kafirin coagulates easily, while an alcohol solution of zein does not coagulate when heated. Kafirin differs conspicuously from zein in the percentage of amide and basic nitrogen, being 3.46, 2.97 and 1.04 and 0.49 per cent. respectively. A further difference exists between kafirin and zein in the proportion of the diamino acids which these proteins yield. Kafirin contains lysine and tryptophane, both of which are lacking in zein, and which are necessary for animal nutrition.

D-MANNOKETOHEPTOSE: A NEW SUGAR FROM THE AVOCADO.[2]

By F. B. LaForge.

[ABSTRACT.]

THE ripe fruit of *Persea gratissima* contains a ketose of seven carbon atoms which was isolated in the crystalline condition and found to be d-mannoketoheptose. Its formula was established by analysis of its bromphenyl hydrazon and phenyl osazon and by a comparison of the latter derivative with the osazon of mannoaldoheptose; also by the fact that it yielded the two epimeric mannoheptits on reduction with sodium amalgam. The melting-point of the new sugar was 152° and its specific rotation + 29°. It was not fermentable with yeast and was not changed by bromine in aqueous solution. This is the first heptose to be found in nature.

[1] *Journal of Biological Chemistry*, vol. 28, 59 (1916).

[2] *Journal of Biological Chemistry*, vol. 28, 2 (January, 1917).

THE FRANKLIN INSTITUTE

(Proceedings of the Special Meeting held Monday, June 25, 1917.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 25, 1917.

VICE-PRESIDENT COLEMAN SELLERS, JR., *in the Chair.*

The Chairman announced that the meeting was called for the purpose of transferring certain property devised to the Institute by the late William H. Wahl to the Institute's Board of Trustees and called upon Mr. Louis E. Levy to present the necessary resolution.

Mr. Levy then offered the following resolution:

"*Resolved*, That the title to premises 1806 Harlan Street, in the City of Philadelphia, being a part of the devise to The Franklin Institute for the Promotion of the Mechanic Arts under the will of William H. Wahl, deceased, and known as the 'John H. Wahl Fund,' be conveyed to the Trustees of The Franklin Institute in accordance with Article I, Section 1, of the By-Laws of the Institute, and that the President and Secretary be, and they are, hereby authorized and directed to execute the deed for the same."

After being duly seconded it was passed unanimously.

Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, June 6, 1917.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 6, 1917.

MR. WM. CHATTIN WETHERILL *in the Chair.*

The following report was presented for first reading:

No. 2694.—Lewis Machine Gun.

The following report was presented for final action.

No. 2687.—Brinell Meter. Recommended that Edward Longstreth Medals of Merit be awarded to Albert Ringland and Frank H. Schoenfuss, of Philadelphia, Pa., for their joint invention of this device.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, June 13, 1917.)

RESIDENT.

MR. EDWARD J. BRADY, Engineering Research, The United Gas Improvement Company, 3101 Passyunk Avenue, Philadelphia, Pa.

MR. WALTER F. HAGER, JR., Manufacturer, Secretary and Treasurer, Keystone Screw Company, Seventeenth and Lehigh Avenue, Philadelphia, Pa.

NON-RESIDENT.

DR. RAIMUNDO CABRERA, Hotel Martinique, New York City, N. Y.

CHANGES OF ADDRESS.

MR. JOHN W. BRASSINGTON, 251 Oak Street, Holyoke, Mass.

MR. JOHN A. CAPP, 62 Bedford Road, Schenectady, N. Y.

DR. DAVID T. DAY, 715 N. Nineteenth Street, N. W. Washington, D. C.

MR. S. L. HAYES, West Point, Ga.

MR. C. P. LANDRETH, Electrolytic Purification Company, southwest corner Fifteenth Street and Lehigh Avenue, Philadelphia, Pa.

MR. C. L. MCILVAINE, 1925 North Second Street, Harrisburg, Pa.

MR. ROBERT S. REDFIELD, Barnstable, Mass.

MR. W. H. SHARP, 1811 Chestnut Street, Philadelphia, Pa.

MR. VICTOR W. ZILEN, Route No. 1, Box 139, Chattanooga, Tenn.

NECROLOGY.

Mr. G. W. Creighton, General Superintendent, Eastern Pennsylvania Division, Pennsylvania Railroad Company, Altoona, Pa.

LIBRARY NOTES.

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DURAND, W. F.—Practical Marine Engineering. 1917.

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Georgia School of Technology, Catalogue, 1916–1917. Atlanta, 1917. (From the School.)

Goodell-Pratt Company, Tool Book No. 13. Greenfield, Mass., no date. (From the Company.)

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Harvard University, Descriptive Catalogue, 1916–1917. Cambridge, Mass., 1917. (From the University.)

Institution of Civil Engineers, Minutes of Proceedings, vol. ccii. London, 1917. (From the Institution.)

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Minnesota Railroad and Warehouse Commission, Thirty-second Annual Report, 1916. St. Paul, 1916. (From the Commission.)

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BOOK NOTICES.

PRELIMINARY MATHEMATICS, by Prof. F. E. Austin, B.S., E.E., Hanover, N. H. Published by the Author, 1917. IV + 169 pages. 4½ x 7½ inches. Price, $1.20.

The vocational or trade school student generally desires to abbreviate as far as possible the highly essential mathematical preparation prescribed as a prerequisite to the pursuit of the professional subjects of his course of study. As many such courses are conducted, there is scarcely any valid reason why this preparation should not be quite brief, in keeping with the elementary, but none the less practical, character of subsequent study. Moreover, the students in these special courses are often making their first acquaintance with mathematics, and a brief course covering considerable ground is an efficient means of giving a quick insight into its practical application and a stimulating method of inducing further study.

Preliminary mathematics is designed on this plan and covers the elements of arithmetic and algebra usually taught in the lower schools. In accordance with modern ideas, the two subjects are developed to-

gether, except in the opening chapters on fundamental notions of number and arithmetic operations, but throughout all succeeding presentations the relationship between numerical and algebraic operation is kept in sight.

Modern text-books on algebra make free use of graphs to visualize in a convincing manner the meaning of positive, negative, and imaginary quantities, and variables and functions. For some reason the author appears to have studiously avoided such diagrams. Imaginary quantities, however, are not mentioned. It is perhaps difficult to include in an abbreviated text everything that may seem needful to the varied types of users, and omissions of matter to meet particular requirements are inevitable. For instance, among others, an explanation of maxima and minima of second-degree functions would be exceedingly useful to many users. The book contains a large number of problems and an unusually large number of them worked out in detail, a feature of value to the student depending wholly on his own resources. The addition at the end of the volume of several college entrance examination papers with their solutions supplies a satisfying test of progress.

LUCIEN E. PICOLET.

THE METHOD OF ENZYME ACTION, by James Beatty, M.A., M.D., D.P.H., with an introduction by Professor Starling, M.D., Sc.D., F.R.S. Philadelphia, P. Blakiston's Son and Company, 1917. 138 pages and index, 8vo. Price, $1.75 net.

This work, written and printed in England, is an interesting example of how the scientists of that country, even in the storm and stress of a struggle greater than any that it has had to encounter since the days of the Armada, can yet find opportunity to discuss the most intricate problems, for the topic covered by the book is one of the most complex and difficult of all physical sciences, withal among the most important. The book reflects vividly however, the actual situation, for Professor Starling, who writes the introductory, is now Lieutenant-Colonel Starling, and dates his contribution from Salonika in January of this year. The world has long been familiar with two letters written to the people of that region; here is a very different type of letter written from that region and marking a great change.

The scope and general character of the book can be briefly set forth by a quotation from Professor Starling's introductory:

"Life can be regarded as a development in the presence of the two essentials, air and water, probably under the influence of the energy of the sun's rays. Since the majority of vital processes are associated with some form of ferment action, which in turn is always connected with the mobilization and shifting of HO and H ions, life itself may be regarded as the dynamical history of water."

The essay is an attempt to explain this mobilization. Space does not permit the setting forth of the manner and method in which the author proceeds with his task. The work is an interesting and useful addition to the literature of an important and difficult phase of biologic chemistry.

HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

Shop Expense, Analysis, and Control, by Nicholas Thiel Ficker, consulting industrial engineer and lecturer on factory engineering and cost production at New York University, School of Commerce, Accounts, and Finance. 236 pages, plates, tables, 8vo. New York, Engineering Magazine Company, 1917. Price, $3.

Principles of Agricultural Chemistry, by G. S. Fraps, Ph.D., chemist, Texas Experiment Station, Agricultural and Mechanical College of Texas; state chemist. 501 pages, illustrations, 8vo. Easton, Penna., The Chemical Publishing Company, 1917. Price, $4.50.

The Microscope: An Introduction to Microscopic Methods and Histology, by Simon Henry Gage, Professor of Histology and Embryology, Emeritus in Cornell University. Twelfth edition, rewritten. 472 pages, illustrations, 8vo. Ithaca, N. Y., Comstock Publishing Company, 1917. Price, $3.

Ontario Bureau of Mines, twenty-fifth annual report, 1916, vol. 25, part i. 311 pages, illustrations, plates, maps, 8vo. Toronto, King's Printer, 1916.

The Life of Robert Hare, An American Chemist (1781-1858), by Edgar Fahs Smith, Provost of the University of Pennsylvania. 508 pages, portrait, plates, 8vo. Philadelphia, J. B. Lippincott Company, 1917. Price, $5.

Reports of the Progress of Applied Chemistry, issued by the Society of Chemical Industry, vol. i, 1916. 335 pages, illustrations, 8vo. London, The Society, 1917. Price, 5 shillings 6 pence.

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Concrete Tile for Land Drainage. 12 pages, illustrations, 8vo. Chicago, Portland Cement Association, 1917.

The Utilities Magazine, March, 1917, vol. ii. No. 2. Philadelphia, The Utilities Bureau, bimonthly. Price, $5 per year.

CURRENT TOPICS

Development of the Coherer. E. C. GREEN. (*General Electric Review*, vol. xx, No. 5, May, 1917.)—The electric wave detecting device, first known as the Branly tube and later as a coherer, has been the subject of much research. Many experimenters in past years noticed that a number of metals, when powdered, were practically non-conductors when a small electromotive force was impressed on the loosely-compressed particles, while they became good conductors when a high electromotive force was applied. This knowledge can be traced as far back as 1835 to Monk of Rosenschoeld, who described the permanent increase in conductivity of a mixture of tin filings, carbon, and other conductors caused by the discharge through them from a Leyden jar. At various subsequent intervals the subject was further studied by C. Varley, S. A. Varley, Prof. D. E. Hughes, and Prof. T. Colzecchi-Onesti. Hughes, while engaged in research work on the microphone, seems to have discovered the important fact that zinc and silver filings placed loosely in a tube of glass were sensitive to electric sparks at a distance, as indicated by their sudden change in resistance.

In 1890, Prof. E. Branly, of Paris, published an account of a very comprehensive series of observations on the same subject that confirmed the work of previous observers and added a great deal of new information. While Professor Hughes seems to have discovered that loose masses of powdered conductors are sensitive to electric sparks at a distance, it remained for Professor Branly to make conclusive observations and thoroughly demonstrate this fact. Branly's work did not secure the notice it deserved until 1892, when Dr. Dawson Turner described Branly's experiments and his own additions to them. Up to June, 1894, when Sir Oliver Lodge described the Branly tube in a lecture before the Royal Institution and first gave it the name "Coherer," it was found to be a very capricious instrument; in instances highly sensitive to electric sparks, and then, all conditions being apparently the same, it became far less sensitive. The metals forming the most reliable coherers were iron, steel, copper, brass, and zinc, while the noble metals were much less reliable.

The man who really made the coherer famous, Guglielmo Marconi, began his work in Italy in 1894, and devoted his attention to the development of the Branly coherer. He made a systematic study of various coherer materials and selected for his work a mixture of 95 per cent. nickel and 5 per cent. silver filings carefully sifted to the same degree of fineness. He succeeded in producing a much more sensitive and reliable electric wave detecting device than had previously been designed. Marconi then proceeded to work out

devices for employing his improved coherer as a relay upon a relay in a telegraphic outfit for receiving wireless messages. This last application caused world-wide interest in the coherer, and numerous experimenters began work upon it. Decoherence was produced in the metallic filings coherer by tapping, slowly revolving the tube. T. Tomasina was the first to use magnetic means directly for producing decoherence. He placed an electromagnet over the tube and in series with the coherer so that when it became sensitive the magnet was energized and lifted the granules to the top of the tube, thus producing decoherence. This method has been applied to a coherer developed by the General Electric Company, to be used in connection with discharge alarms for lightning arresters, high-frequency alarms, etc.

The New Military Rifle. A. B. BOWERS. (*Scientific American*, vol. cxvi, No. 19, p. 474, May 12, 1917.)—The regular army rifle, while in most respects an admirable weapon, is, in the opinion of many competent observers, open to grave objections on more than one ground. In the first place, the trigger by which the rifle is discharged is located below the stock, between narrow, open-sided guards, which are far from sufficient protection. Moreover, the manner of discharge, by pressure of the forefinger on the trigger, produces in many cases a sidewise and downward movement of the whole barrel sufficient materially to affect accuracy of aim. A far greater measure of inaccuracy in shooting is caused by the short distance between the sights. The back-sight is too far forward—from 12 to 18 inches from the eye. This defect cannot, however, be remedied off-hand, for, with the open back-sight used, this distance is necessary for accurate focussing of the two sights upon the target. Again, many users of rifles carry them at full cock so that they may be ready for instant use by releasing a locking device. Finally, in cold weather the gloved finger is too stiff to manipulate with safety the trigger now in use.

A Brooklyn inventor claims to have eliminated these various defects in a new gun recently patented. He has substituted for the old projecting finger-trigger under the stock a thumb-trigger above the stock. In operation it is only necessary to tighten the grip of the hand slightly in order to work this trigger; and at rest it is possible to guard it by a five-sided guard. A long-sighting range has been obtained, without any of the disadvantages enumerated, by attaching a peep-sight to the firing pin. In this way a broad base is obtained sliding in closely-fitting guards that preserve the alignment. Not only does this give the desired long-sighting range, but, bringing the back-sight to within four inches of the eye, it permits the use of a peep-sight small enough to insure accurate aim. The conflict between cocking and locking is automatically eliminated, for the base of the peep-sight so completely covers the thumb-trigger, when the gun is at cock, that the necessity

for locking is wholly removed. Finally, the motion by which the discharge is accomplished is such a simple one that it can be made without the slightest difficulty, regardless whether the hand be bare or gloved.

Industrial Lifting Magnets. J. VICHNIAK. (*Le Genie Civil*, vol. lxx, No. 16, p. 253, April 21, 1917.)—The application of electro-magnets to replace the familiar crane hook in handling iron and steel materials has proved of great value in materially reducing the labor entailed in moving about such material in the course of manufacture. Although the principle of the lifting magnet is very simple, it was only after much experimenting that a practical design was evolved adapted to the rugged requirements of rapid handling. The calculation of lifting power for materials with plane surfaces is not complicated, as the total flux and strength can be easily computed. When, however, objects of irregular shape are dealt with, it is only by tentative methods that the best proportions of the magnet can be found for a given class of material.

The lifting magnet is particularly useful for material not easily shackled, such as chips from machine tools, various structural discarded odds and ends, and also to material of regular shape of moderate weight. One unique application is in handling hot billets. These pieces, difficult to attach to the ordinary crane hook when hot, are readily raised and removed by the magnet. Special water-cooled magnets are empoyed for this service. It is well understood that the capacity depends upon the proximity of the piece to be lifted to the pole face. To increase the capacity when lifting irregular pieces, the Couffinal works at Saint-Etienne have designed a magnet with subdivided vertically movable pole faces. These subdivided faces, by their vertical movement, conform to the irregularities of the pieces lifted and prevent lateral motion, as well as increase the lifting capacity. Another special form of magnet for lifting a bundle of rods or other long pieces is provided with a linkage, somewhat after the manner of a clam-shell dredge bucket, operating arms that embrace the load held by the magnet. Once in place, the magnet is deënergized and the load is transferred to the arms, thus economizing current.

Testing Automobile Engines Electrically. ANON. (*Electrical World*, vol. 69, No. 12, p. 557, March 24, 1917.)—The use of the generator for engine testing is in itself an old device, yet there is much of novelty in the technical applications of this famliar process in the testing-room of the Toledo plant of the Willys-Overland Company. The first steps in the testing process are to mount the engine on the testing block and drive the engine at 500 r. p. m., using the generator as a motor. This overloads the motor by some 300 per cent. for a very brief period, perhaps one to three minutes, at the end of which time the friction load drops

to normal. Then follows a half hour's run at the same speed, with a further decrease of load to about 20 per cent. its full value. At this point the speed is increased to 700 or 800 r. p. m., at which it is kept for an hour to an hour and a half, until the engine is fairly down to its proper friction load. The operation is then reversed, the engine driving the electric machine as a generator and delivering energy to the line. Next it is throttled, for half an hour to an hour, to about half load on the generator; then the full load and speed are maintained for an hour. By this duplicate process it is made certain that the engine is fully down to its normal performance before it is installed in the car, and the load of some of the engines is utilized to supply mechanical power for breaking the others to their bearings.

The test-room, which is 120 feet square, contains 100 engine-testing stands arranged in ten rows of ten stands each. Each set includes a 10-h. p., 500/1200 r. p. m., 230-volt, direct-current Westinghouse type S. K. shunt-wound generator, semi-enclosed on the commutator end, and a panelboard carrying control equipment and an ammeter. The great practical advantage of this testing system is not only to save power by the double use of the machines, but particularly in the rapidity and facility in which the tests can be executed. The output of the testing-room is double that with brake equipment, and the quietness of operation resulting from the absence of belts and brakes gives the operators a better opportunity to observe the working of the engine.

Brightness and Contrast. J. KERR. (*The Illuminating Engineer*, vol. x, No. 2, p. 41, February, 1917.)—For a couple of generations or more it has been known that the eye has great power of adjustment in relation to light: a power called *adaptation*. Adapation had scarcely been sufficiently considered in practice and was not clearly defined as the essential factor in differences of lighting till the Society's initial investigations in 1909–1910, dealing with the subject of glare, were conducted. At that time the view was held that the range of adaptation, measured by the sensitiveness of the eye attained in the dark, was twenty or thirty times its sensitiveness in daylight. This estimate has been continually raised by almost every worker in the last half-dozen years, and in the report of a committee of the American Society of Illuminating Engineers it is stated that visual sensibility is fully a million times as great after half an hour's rest in darkness as in broad daylight. Adaptation depends upon the mechanism of the retina and is quite distinct from *accommodation* of the eyes by the lens and the action of the iris.

In any exact vision the eyes are constantly being centred so as to bring the image upon certain sensitive little spots on the retina, the rest of the retina merely giving rough orientaton. In reading, the eyes go along a line in a series of little jumps, fixing a series

of such spots in succession, not necessarily in contact, but sufficiently near to give hints of words which the brain can use. For exact work, the more nearly monochromatic the light (with its absence of chromatic aberration), the clearer the image. Too poor an image on the retina may be caused by inadequate light, insufficient contrast, by retinal conditions, or by veiling from the glare of extraneous light, as from a shiny page.

Apparently the maximum brightness for which the eye is prepared through its long course of evolution is the brightest sky, apart from the actual image of the sun. This amount is generally taken at 2.5 to 3 candles to the square inch, and some such amount has been suggested as the standard for any visible sources of light. Indirect lighting may accomplish this. Indirect lighting owes its restfulness to its diffuseness and absence of high intrinsic brilliancy on any surface. The eye is saved much fatigue by absence of violent contrasts and by not having to pass from a comparative dark surface to an incandescent one quite suddenly. On the other hand, it is only through shadows that objects are seen; comparatively shadowless lighting, while useful for general illumination or examination of plane surfaces, reading or writing, is not so useful where small objects or textural surfaces have to be examined. Direct lighting is the most economical method for handling objects or manufacturing processes, but the light source should be kept out of the field of vision or shaded down to the 3-candle-power-per-inch standard.

The matter of contrast which enters into the problem of illumination is of great importance in insuring clear vision; excessive or deficent contrast may be equally troublesome. Experiments in the United States indicated that vision is best with contrasts about 1:20, but was possible at 98:100. In sunlit scenes out-of-doors, excluding the sun itself, contrasts rarely exceed 1:20, indoors not over 1:200, although window frames against a bright sky may give a contrast 1:10,000. Experience suggests that the ratio be kept below 1:100. In full daylight, with the eye adapted to relatively great brightness, even an incandescent filament may not appear very glaring, whereas in the dark a lighted match held near the eye produces a temporary dazzle. In cinema theatres the illumination of the screen will be found to vary from 0.5 foot-candle to 1 foot-candle or more. The ratio 1:100 would imply brightness of surroundings of about 0.01 foot-candle, extreme contrast between the brightness of the screen and the general surroundings being objectionable.

The Photometry of Luminous Substances. A. BLOCK. (*The Illuminating Engineer,* vol. x, No. 3, p. 76, March, 1917.)—The measurement of the brightness of fluorescent and phosphorescent substances is rendered difficult by two factors: (1) the color of the light, the spectrum of which usually consists of bands or lines

situated mainly in the green or the blue; and (2) the relatively low luminosity. Both these factors tend to introduce the Purkinje effect. Fortunately the chief data required are usually relative, and one can thus work throughout with a colored screen placed in front of the comparison lamp, and designed to give a color which more or less matches the light of the material being tested.

If absolute values of brightness are desired, allowance must be made for the absorption of the screen, but the procedure for effecting this introduces all the physiological difficulties attendant on heterochromatic photometry at low illuminations. An approximate color match can be obtained with relative ease, for example, by the use of signal green glass in testing phosphorescent zinc sulphide. But, unless the spectral composition of the two lights compared is substantially identical, errors may be introduced by the order of luminosity at which the test is made, the part of the retina upon which the image is received, and perhaps, also, by the size of the photometric surface employed. Various photometric methods have been devised for dealing with this class of substances, and in these a color-matching screen is almost always employed.

A point to be borne in mind in speaking of photometrical values of self-luminescent substances is that the luminosity of the material in powder form is considerably higher than when the material is mixed with varnish or other substance to form paint. Moreover, the thickness of the layer tested to some extent determines the foot-candle value. A further factor which may influence the result is the treatment of the substance in regard to exposure to light before the test. In the matter of substances like Balmain's compound this is obviously a matter of prime importance, but with materials depending on radio-active excitants for their luminosity the effect of previous light action is apparently not yet thoroughly known. It is indeed very evident that for the systematic specification of these self-luminous substances standard test conditions still remain to be worked out.

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